Intelligent path planning to mitigate obstacles and deliver products using a modified A* algorithm

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Abstract – Computational advances in micro unmanned aerial vehicles (UAVs) with monocular camera is huge. A micro unmanned aerial vehicle, or drone, is a flying machine that typically has a camera and ranges in size from small toy drones to large military aircraft. The task of controlling these machines often requires the use of path-planning algorithms. Lots of work focuses on path planning with that monocular camera in real-time [11], but it is very difficult to accomplish with conventional methodologies. In detail, the suggested method is based on the efficient search algorithm used to find the optimal path between two nodes in a graph also it is an extension of Dijkstra's shortest path algorithm. The proposed paper presents a novel approach for efficient and effective path planning of drones using a modified A* algorithm. The primary objective of the algorithm is to find the shortest and safest route from the source to the destination, while also minimizing the likelihood of collisions or accidents during the flight. To accomplish this, the algorithm employs a technique of creating a maze of the location where the drone is to be flown, which serves as a visual representation of the obstacles and potential hazards in the environment. The modified A* algorithm considers the unique features and capabilities of drones, such as their ability to fly over obstacles, hover in place, and change direction quickly. The algorithm considers the drone's flight dynamics, including its maximum speed, turning radius, and battery life, to find the optimal path that meets these requirements. Moreover, the algorithm incorporates a set of heuristics that reduce the computational complexity of the search, resulting in faster and more efficient path planning.

Keywords – UAVs, path planning, A* algorithm

I. INTRODUCTION

UAVs have revolutionized the process of acquiring geographic data and mapping land resources. With their versatility, UAVs can easily access even hard-to-reach places such as hilly regions, providing many surveying opportunities. UAVs are also increasingly used for package delivery and surveillance purposes, making them versatile tools for many industries. Moreover, the imagery acquired from UAVs is beneficial for large-scale mapping and urban modeling applications. As a result, UAVs have become an essential part of the geospatial industry, making them a crucial factor in gaining insights into land resources and the environment. However, the drawback of the traditional Dijkstra algorithm is that it only considers all options, but A* uses a heuristic function that prioritizes nodes that are thought to be superior to others in its search for a better path. There are other methods of route planning in UAVs, some of which are reinforcement learning [3] and swarm intelligence [2].

Learning effectively from small samples is a major difficulty with reinforcement learning. Sample efficiency is the measure of how much experience an algorithm must acquire during training to achieve an efficient performance. This makes it essential for the algorithm to make use of the provided sample to be effective. Therefore, finding ways to increase sample efficiency is essential for successful reinforcement learning. Developing algorithms that can learn quickly and effectively from small data sets is a challenging but vital task for research into reinforcement learning. Moreover, the difficulty of ensuring sample efficiency can be addressed by improving the learning models or using techniques such as transfer learning.

The ability to use fewer samples while still achieving accurate results can provide great benefits and reduce costs in many applications. Local search techniques like traveling salesman algorithms (TSP) are also used in many places for planning routes [1]. TSP frequently prioritizes choosing the least expensive option over determining the best course of action.

Because TSPs are complicated, determining the shortest path is challenging, which increases the attractiveness of approximative, rapid, and inexpensive solutions. The A* algorithm is one such solution that has been used for path planning in TSPs, by using this algorithm, it creates the shortest route possible between source and destination, thus making it easier and more reliable for delivering anything. Furthermore, what makes this algorithm so appealing is that it produces a solution faster than other existing algorithms, while still providing good results. It creates the shortest route between source and destination and aids in delivering anything. Its efficient performance and ability to create the shortest route have made the A* algorithm popular for solving traveling salesman problems.

The proposed approach is made possible through the utilization of an A* algorithm with a heuristic function that enables an efficient path-planning solution. It is expected that this work will be beneficial in finding optimal routes for various applications in real-world scenarios. Section 2 of the paper organizes the entire work and begins by highlighting the related work based on path planning. Section 3 of the paper provides detailed information about the suggested methodology, including implementation details and strategies to make it more efficient. It also talks about how to analyze and compare different results obtained with different parameters and data sets. Section 4 is dedicated to evaluating the performance of the proposed work. It discusses the accuracy, efficiency, and other relevant metrics used to measure its success. Finally, Section 5 provides a conclusion regarding the suggested work. It summarizes all the findings from previous sections and highlights any potential improvements that can be made in future implementations of this approach. The conclusion also provides some possible applications of this technique in areas such as robotics and autonomous navigation systems.

II. RELATED WORKS

Path planning is a process, which requires us to first convert the drone's video feeds into pictures. As stated by R.R.Schultz et al [4] This conversion of spatial and temporal data from a brief visual sequence into a single high-resolution video frame is extremely crucial. It will help in understanding the environment around the drone better for path planning. Furthermore, the data obtained from this conversion helps the drone not only understand its environment but also to identify the most effective route for navigation and path planning. The implementation of image conversion from video feeds has made path planning much more efficient and precise by providing clear and accurate information about the environment.

Therefore, it can be said that video feed-to-image conversion is an essential initial step toward successful path planning. Similarly, Chandra Shekhar Mithlesh et al [5] have used MATLAB to extract high-resolution videos with short low-resolution footage. The process of converting a color image into a grayscale image is a challenging task, as the contrasts, sharpness, shadow, and structure of the color image may be lost in the grayscale version. To overcome these challenges, they have devised a deep learning algorithm that uses convolutional neural networks and transfer learning techniques to detect and reduce noise. As a result, a low-quality video feed is converted to a better-quality image for easy consumption. This approach allows for improved retraining and fine-tuning of the same model for different tasks with fewer resources. Moreover, it can be scaled up to larger datasets and provides better accuracy, which is essential for extracting information from images. C. Saravanan [6] suggests a few strategies to maintain the color image's contrasts, sharpness, shadow, and structure.

To ensure that the integrity of the data remains intact, these strategies should be adhered to strictly. It is important to note that the quality of an image has a direct impact on the accuracy of conclusions made from it. This makes it essential that images are properly collected and transmitted over a channel without any noise. The presence of noise can drastically reduce the quality of an image, making it harder to interpret accurately. Thus, it is important to take necessary precautions while collecting or transmitting an image as even a minor noise can have a significant impact on the overall quality of the image. One should make use of these few strategies suggested by him to maintain the color image's contrasts for the best overall result. Pearl Pullan et al. [7] employed the Median filter, Geometric Mean (GM) filter and Harmonic Mean (HM) filter to recover the observed noisy pixels to remove noise from grayscale images.

Object detection is an important task in many fields, such as security and photography. For object detection, deep learning algorithms are based on neural networks, while traditional ML techniques, such as linear regression, logistic regression, decision trees, SVM, and others, are based on traditional mathematical algorithms. Deep learning benefits are Suitable for issues of extreme complexity. Superior accuracy over traditional ML. To address the limitations of Dijkstra algorithms with tiny heuristics, Cong Tang et al. [8] suggest a filter to recover the observed noisy pixels to remove noise from grayscale images. The filter consists of two steps: first, it filters out all pixels that are not in the training set; and second, it uses a deep learning algorithm to detect the edges between the training set and the observed data. This method is effective at recovering accurate object detections while minimizing the number of required training examples. Path planning is a difficult task that must be performed efficiently to meet the needs of UAVs, robots, etc. Several modified algorithms have been developed to improve the efficiency of the path-planning process. An optimal or almost optimal path is quickly investigated by the algorithm proposed by T. Goto et al. [9], ensuring that the UAVs achieve their intended goal as quickly as possible. Unfortunately, the heuristics don't always keep admissibility and the system doesn't always choose the best course of action.

As a result, there are a few disadvantages in these methods which need to be addressed and leveled up for real-time execution to be feasible. This is where the proposed work comes in. It addresses all the issues present in the existing system, thus making it possible for algorithms to be leveled up and real-time execution to be achieved. The proposed work solves multiple problems and provides a more efficient system than the existing one. It not only helps in leveling up algorithms but also ensures that the system chooses the best course of action and keeps admissibility intact.

III. PROPOSED METHODOLOGY

For the traverse of the trajectory, The video feed from the drone and the sensor signal is used as input for the traversal of the trajectory, which is then pre-processed to extract frames. After that, noise reduction is applied to make sure images are clear and accurate. A matrix is developed based on detected objects in photos taken by the camera onboard the drone; this includes anything from people to trees. Once this has been completed, a virtual version of the said matrix can be created so that any obstructions or open areas can be mapped out with precision. Finally, using an algorithm called A*, a path between the source and destination can be found without having recourse to human intervention The proposed method is shown in Fig. 1.

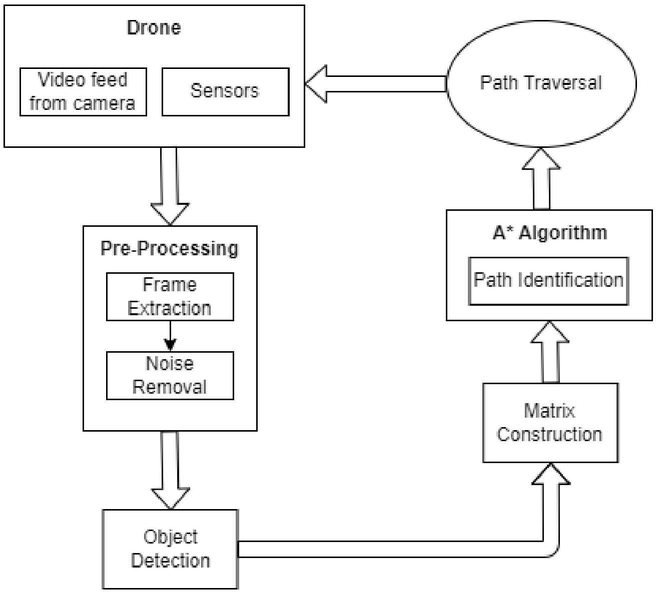

Fig. 1 Proposed methodology

A. *Image Pre-processing*

A crucial step in many computer vision and image analysis jobs is image pre-processing. The quality of pre-processing can greatly affect the performance of subsequent stages, such as feature extraction, classification, or segmentation said Milan Sonka et al[10]. It is important to note that pre-processing is an iterative process and that the results of one stage can influence the parameters used in subsequent stages. It is often necessary to try multiple approaches and fine-tune the parameters to obtain the best results. There are many steps in image pre-processing. They are as follows.

- Image acquisition is a crucial step in the image processing pipeline and refers to the process of obtaining an image. This can be accomplished through various methods such as using digital cameras, smartphones, or scanners, here it is UAVs. Similarly, if the image is being captured from a moving platform, it may be necessary to use image stabilization techniques to reduce motion blur. After acquiring an image, it is often necessary to perform some basic pre-processing steps such as cropping, resizing, or color correction. These pre-processing steps help to improve the quality of the image and increase the accuracy of image processing algorithms.
- Cropping, resizing, and color correction are three important pre-processing steps that are often used in image processing. Cropping is the process of removing unwanted parts of an image and keeping only the region of interest. This can be useful for removing distracting elements from an image, focusing on a specific object, or adjusting the aspect ratio. Resizing is the process of changing the size of an image to a different resolution. This can be necessary to reduce the computational complexity of image processing algorithms or to adjust the image to a standard size. Bilinear or bicubic interpolation is often used to resize images while preserving image quality.

$$\mathbf{G} = \sqrt{{\mathbf{G}_x}^2 + {\mathbf{G}_y}^2} \tag{1}$$

- Color correction is the process of adjusting the colors in an image to ensure they are consistent and accurate. This is particularly important for tasks such as object recognition, where color information is used to distinguish between different objects. Color correction can be performed using various techniques, including color balancing, histogram equalization, or color normalization. By carefully considering these pre-processing steps and choosing the appropriate techniques, it is possible to enhance the image's quality and increase the accuracy of image processing algorithms.

$$D(x, y, \sigma) = L(x, y, k_i\sigma) - L(x, y, k_j\sigma) \tag{2}$$

B. *Object Detection*

Deep learning algorithms have significantly improved accuracy and speed in the field of object recognition in recent years. In this study, object identification techniques are used, including conventional techniques like edge detection and template matching as well as deep learning-based methods like single-shot detectors (SSDs), region-based CNNs, and YOLO systems. The goal of object detection is to identify the presence of objects in an image or video frame and to determine the position of each object. Object detection has many practical applications like path planning for UAVs, autonomous driving, video surveillance, and image retrieval.

- Traditional object detection methods can be divided into three main categories: edge detection, template matching, and feature-based methods. Edge detection is based on the idea of finding the lines separating things from the backdrop. The Canny edge detection technique uses four filters to find edges in the distorted image that are horizontal, vertical, and diagonal since an edge in an image might point in several different directions. The first derivative in both the horizontal direction (Gx) and the vertical direction are both given by the edge detection operator as values (Gy). This allows for the determination of the edge gradient and direction. The gradient magnitude of an image to detect edges, and is given by the following formula:

- Feature-based methods extract features from the image, such as corners or edges, and use them to detect objects. In the Scale-Invariant Feature Transform algorithm, The input image is filtered using the Difference of Gaussian (DoG) pyramids to detect local extrema in scale and space. The detected extrema are refined to obtain sub-pixel accuracy and eliminate low-contrast responses. For each key point, a local orientation histogram is computed, and the dominant orientation is assigned to the key point. A set of descriptors is computed for each key point based on the gradient information in its local neighborhood, resulting in a descriptor vector for each key point. The descriptors for two images can be compared to determine the corresponding key points in the images. Overall, SIFT is a powerful and widely used method for feature detection and description in computer vision. The algorithm can robustly detect and describe local features, even in the presence of significant affine or photometric distortions. Specifically, a DoG image is given by

C. ***Matrix Construction***

Following the discovery of the artifacts, the impediments are indicated and the remaining areas are made clear. In the suggested work, we have virtually constructed a maze. The virtual maze that has been constructed in the suggested work serves as a simulation environment for the path-planning process. The green hue in the maze represents the destination or the goal that the path planner needs to reach. This destination acts as the endpoint for the path-planning process. On the other hand, the starting point of the path-planning process is denoted by the diagonal across from the green hue. This diagonal serves as the starting point for the path planning algorithm and the algorithm is expected to find a path from this point to the green hue, which represents the final goal. The virtual maze provides a controlled environment for testing the path-planning algorithm and evaluating its performance. The maze can be designed in different configurations to test the algorithm's ability to handle different types of challenges such as obstacles, narrow passages, and more. The virtual maze can be easily modified to test the robustness and efficiency of the algorithm. In addition, the virtual maze provides a visual representation of the path-planning process, making it easier to understand and interpret the results. In conclusion, the virtual maze is a crucial component of the suggested work as it provides a controlled environment for testing the path planning algorithm and evaluating its performance. A virtual maze is an effective tool for understanding the behavior of the path-planning algorithm and improving its performance. The following Fig. 2. Shows the matrix created for some sample data.

D. ***Path Identification***

In this suggested work, the A* algorithm, a well-known path-planning technique, is utilized to determine the best route between the beginning point (represented by the diagonal) and the desired outcome (denoted by the green hue). To identify the best path, the A* algorithm combines the most advantageous aspects of the two well-known algorithms Dijkstra's algorithm and Best-First Search. The projected cost of the path from a specific node to the end objective is evaluated using a heuristic function, and to find the most effective route, the cost of the journey up to that point is balanced against the estimated cost of achieving the goal. To determine the best route between the start and the desired outcome, the A* algorithm is used in the virtual maze. It takes into account every scenario before deciding on the best route to the end result. Fig. 2 presents the path that the algorithm came up with as a consequence, giving the journey a graphical presentation. As a result, the proposed work's usage of the A* algorithm provides an efficient approach to determining the best route through the virtual maze between the beginning point and the ultimate destination. The algorithm is a good option for path planning in complicated situations since it can handle complex circumstances and determines the ideal path quickly. Some of the examples are shown in Fig. 3 and Fig. 4

IV. PERFORMANCE EVALUATION

Evaluation results are important in path planning projects as they help to assess the performance of the algorithm and determine its strengths and weaknesses. The evaluation results can be used to compare different algorithms, evaluate the performance of an algorithm in different scenarios, and identify areas for improvement.

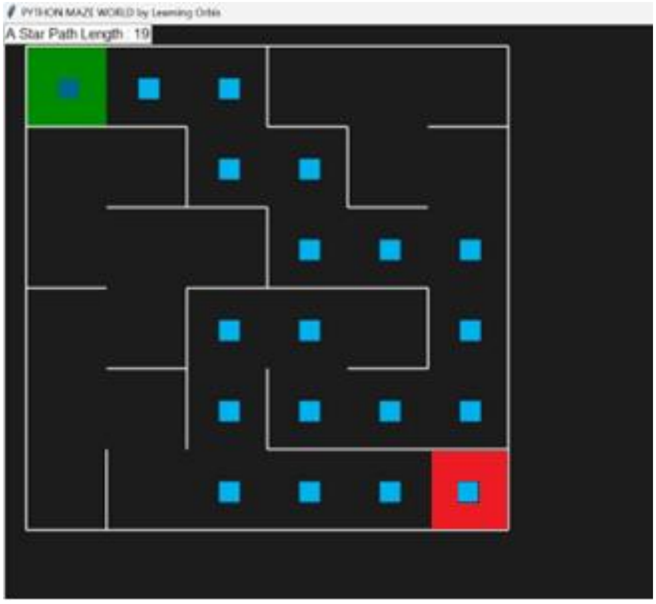

Fig. 2 Matrix construction

Fig. 3 Drone Travelling on the path identified

Fig. 4 Drone Traversal by mitigating obstacles

*A. **Datasets***

Only a few generally accessible datasets are acceptable for the suggested path-planning method. This work applies to recording several videos using the Tello drone to test the suggested techniques.

B. *Evaluation results*

The optimality score measures the percentage of successful path-planning trials. A high optimality score indicates that the algorithm is successful in finding a path to the final goal in most scenarios and this metric is satisfied in most of the trials. The size of the matrix indicates the dimensions of the matrix created which is used for testing purposes. The number of samples indicates the trial runs in a particular matrix arena. Average execution time indicates the time taken by the machine to run the algorithm and find the most optimal path. The path accuracy is found based on parameters such as whether the path found, is the most optimal path, the least complex path, and the time taken for the algorithm to find the path. A smooth path is important for real-world applications, as it reduces the risk of accidents and increases the efficiency of the path. The overall accuracy of the algorithm is around 92.6%

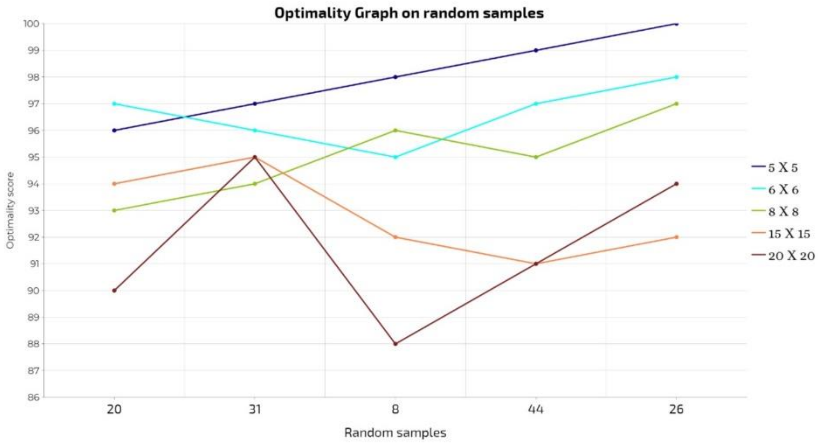

Fig. 4 Graph representing Optimality score for various samples

Table 1. Table containing optimality score and path accuracy for various area.

Area	Number of samples	Avg. Execution time	Path accuracy	Optimality score
5 X 5	200	64.5 s	98.5 %	98/100
6 X 6	180	74 s	95 %	96.8/100
8 X 8	120	81.6 s	92 %	95/100
15 X 15	100	140 s	89.5 %	93/100
20 X 20	50	256 s	88 %	92/100

V. Conclusion and Future Work

In conclusion, path planning is an important aspect of robotics and autonomous systems, as it enables these systems to navigate from one point to another in a safe and efficient manner. The use of algorithms such as the A* algorithm has proven to be effective in finding optimal paths in complex environments. However, there is still room for improvement in path planning, and future enhancements are necessary to address the challenges posed by real-world scenarios. Some potential future enhancements for path planning include:

- Integration of machine learning techniques: Machine learning algorithms can be integrated into the path planning process to improve its performance in complex and dynamic environments. For example, reinforcement learning algorithms can be used to learn from previous experiences and adapt to changing conditions.

- Incorporation of real-time constraints: The path planning process can be enhanced to take into account real-time constraints, such as the presence of obstacles or other vehicles. This will enable the algorithm to find safe and efficient paths in real-time environments.

- Development of hybrid algorithms: Hybrid algorithms that combine different path-planning techniques can be developed to address the challenges posed by complex and dynamic environments. For example, a hybrid algorithm that combines the A* algorithm with reinforcement learning can be used to find optimal paths in real-time environments.

future enhancements in path planning will focus on improving the efficiency and effectiveness of the path planning process. The incorporation of machine learning techniques, consideration of real-time constraints, and development of hybrid algorithms are just some of the potential areas of improvement. These advancements will lead to more sophisticated and reliable path-planning systems, which will be crucial for the success of robotics and autonomous systems in real-world applications.

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