MADHAV INSTITUTE OF TECHNOLOGY & SCIENCE, GWALIOR

(A Govt. Aided UGC Autonomous & NAAC Accredited Institute Affiliated to RGPV, Bhopal)

Project Report

on

Path-planning for UAVs using Particle Swarm Optimization

A project report submitted in partial fulfilment of the requirement for the degree of

BACHELOR OF TECHNOLOGY

in

INFORMATION TECHNOLOGY

Submitted by:

Kunal Patker

0901IT181031

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Faculty Mentor:

Dr. Saumil Maheshwari, Assistant Professor

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CERTIFICATE

This is certified that **Kunal Patker**(0901IT181031) has submitted the project report titled **Path-planning for UAVs using Particle Swarm Optimization** under the mentorship of **Dr. Saumil Maheshwari**, in partial fulfilment of the requirement for the award of degree of Bachelor of Technology in **Information Technology** from Madhav Institute of Technology and Science, Gwalior.

27-05-22

Dr. Saumil Maheshwari
Assistant Professor
Information Technology

27.5.22

Dr. Akhilesh Tiwari
Professor and Head,
Department of IT

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DECLARATION

I hereby declare that the work being presented in this project report, for the partial fulfilment of requirement for the award of the degree of Bachelor of Technology in Information Technology at Madhav Institute of Technology & Science, Gwalior is an authenticated and original record of my work under the mentorship of **Dr. Saumil Maheshwari**, Assistant Professor, Information Technology. I declare that I have not submitted the matter embodied in this report for the award of any degree or diploma anywhere else.

Kunal

Date: 27 May 2022

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Kunal Patker

0901IT181031

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Kunal Patker

0901IT181031

IV Year,

Information Technology

ABSTRACT

In today's modern era, whenever we talk about anything, it is always about automation. At the time of the present scenario, the most talked-about uncrewed vehicles, and UAVs (in the case of air). We have presented a solution for finding a path in an environment with dynamic and static objects because during practical executions of operations they perform various types of manoeuvres for a change of direction and other necessary operations. The aim is to find a cost-efficient ideal flight path in the environment to progress in a path with no collision, which is inspired by nature. This report presents the use of Particle Swarm Optimization (PSO) combine with cubic spline interpolation for Path-Planning . PSO works on the concept of flocking behaviour of birds and fish schooling. Every bird in a group of birds is dedicated to finding its food and prey. If someone finds the prey, then it will share all the information with the other birds in the group for an optimal path to it. They follow the optimal path in a controlled and guided manner, like a swarm. It is used instead of other meta-heuristic optimization algorithms because of its accuracy and also provides a refined convergence rate. A swarm of particles is made to coordinate with each other for ideal path planning. A pre-defined static and dynamic environment is created to perform the simulation. Python is used for the required simulation, and the algorithm is applied according to path cost or length, which should be the minimum. The whole simulation is done with a particle population of 100 and 500 iterations of the algorithm.

Keywords: Path planning; Dynamic Environment; Static Environment; Nature-inspired Algorithms; Particle Swarm Optimization; Swarm Optimization

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Chapter 1: INTRODUCTION

1.1 Introduction:

Robots are controlled remotely or onboard computers without any crew or human pilot. They are part of unmanned aircraft systems. In today's time, these things are being used very fast in places where it is difficult or dangerous to go, like rescue operations, monitoring, widely used in the military world, etc. For example, in the field of war, if a person in any plane loses his life due to a crash or aircraft shot down, but if unmanned aerial vehicles (UAVs) are used in his place, then an experienced pilot can be saved. One of the most recent examples is the use of the Bayraktar TB2 drone in the ongoing Ukraine-Russia war, as well as in Azerbaijan and the 2020 Nagorno-Karabakh war. When we talk about unmanned aerial vehicles (UAVs), they have to work in three-dimensional space and they have to plan a path to move forward, also considering the achieved height in complex terrain and also avoiding static and dynamic obstacles in their path. This process becomes more complex and challenging as it requires lots of computation time as they have to work on geometric path generation from the initial start state to the final goal, also considering that the path selected should be cost-efficient too. As technology advances and remotely navigable aerial drones become commercially available, they may begin to be used in some unwanted businesses or terrorism, for which some limitations are also set by high authorities, like the achievable height of the drone and restrictions on flying over no-fly zones as shown in the Figure1.. When unmanned aerial vehicles (UAVs) are flying at high velocity, they should be capable of making instantaneous changes to respond as quickly as possible. Autonomous control modules for unmanned aerial vehicles (UAVs) use a three-dimensional planner to generate an optimal path to travel from the initial base to the goal, avoiding obstacles and flying over no-fly zones. They are quite different from commercial airlines as they follow pre-defined routes. Unmanned aerial vehicles (UAVs) have to do real-time path planning, which includes many complex challenges to solve due to several constraints like air pressure, drag, etc., which may affect the normally desired route followed by the unmanned aerial vehicles (UAVs). It may also affect the sensors of the unmanned aerial vehicles (UAVs), which results in the information gathering limit and causes malfunctions in various electronic instruments that can lead to some severe accidents that result in the loss of capital.

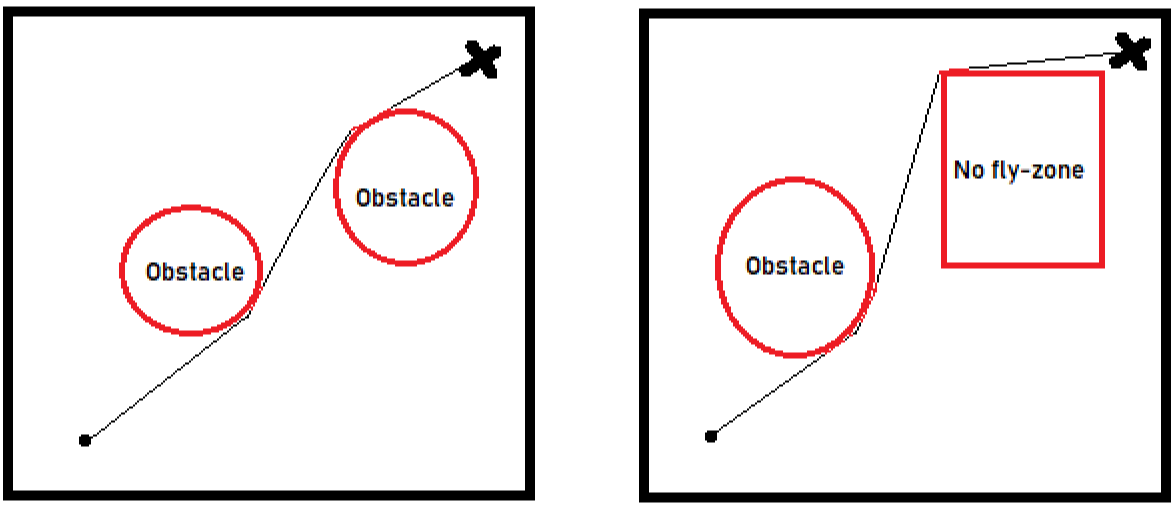

Figure 1. The path that avoids obstacles and no-fly zones

It is a very challenging task to find a reliable solution and guidance system. It comes under the concept of a difficult optimization problem where we have to create or plan a path in a real-time environment without any failures. For that, algorithms are one of the best possible solutions for such logical operations, as they are not hypothetically implemented. A most promising approach should be planned by such autonomous vehicles so that they must reach their goal without collision, even if the goal is in motion or any other conditional scenario. Basically, autonomous robots can be 2-dimensional or 3-dimensional, which are popularly used in the current world. Two-dimensional autonomous control vehicles (ACVs) are autonomous in two ways. Some of their examples are traffic models, lane changing in vehicles, etc. In the case of 3D, the majority are air and water-based. They are equipped with multiple highly sensitive sensors like a 3-axis accelerometer, 3-axis gyroscope, magnetometer, GPS sensor, distance sensor, etc., and a sophisticated programmed path planner that is used to coordinate the vehicle and gives the capability to plan an ideal low-cost effective path. Path planning may be static or dynamic. Static path planning deals with predefined trajectories and is also termed offline path planning, whereas dynamic path planning, in which a path is continuously planned instantaneously, is also termed online path planning. Path planning is done with the help of numerous algorithms in such a way that it creates a more reliable trajectory. There are lots of algorithms or solutions that are present, like the probabilistic roadmap method (PRM), random trees algorithm (RRT), rapidly exploring random trees star (RRT*), expansive space trees algorithm (EST), model predictive control method (MPC), artificial neural networks algorithm (ANN), genetic algorithm (GA), fuzzy logic approach, A*, and D* (Heuristic-based search algorithms), and also some new nature-inspired meta-heuristic algorithms like glowworm swarm optimization (GSO), ant colony optimization, cukcoo search algorithm, particle swarm optimization, etc.

1.2Objective and Feature:

The main aim of the project is to find the most optimal and shortest path for an autonomous robot in a static and dynamic environment, with or without a moving goal. Here we propose a nature-inspired algorithm for path planning to find the optimal solution. Here we use particle swarm optimization combined with cubic spline interpolation. The testing results demonstrate that the improved PSO's path planning has more turning points with a rough path, which will alter the robot's dynamic characteristics when it is moved. As a result, to have a smooth path with the increased robot dynamic adaptability the algorithm needs, it is important to improve the aforementioned improved PSO algorithm further. To create a smooth curve, various interpolation intervals based on cubic polynomials are used to suit the cubic spline curve. for the same. In this project, the edges of the obstacles are not considered inside of them. The main feathear of this is to find an optimal solution for path planning with the use of a particle swarm optimization algorithm that is inspired by nature. Some experiments are done to show how the paths are planned with different lengths from which an optimal path is selected with less length. And some are done to show how the whole process is executed or the final simulation in which the source is travelling through the most optimal solution to its static or dynamic goal without having any collisions throughout its path in the real time environment.

Chapter 2: Literature Review

2.1 Swarm Intelligence

Swarm intelligence is the branch of artificial intelligence, first presented in the year 1989 by G. Beni and J. Wang in the global optimization framework as a collection of algorithms for controlling the automated swarm. Some of the swarm intelligence models that are successfully applied in many real-time applications are Particle Swarm Optimization, Ant Colony Optimization, Glowworm Swarm Optimization, etc.

It is a collective behaviour branch of artificial intelligence in which a group of objects is used to perform tasks in a well-coordinated and disciplined manner, just like a group of birds, ants, etc. In this, every single entity or object in the group contributes their work separately to the solution. This type of technique uses various swarm intelligence algorithms where every object works autonomously. On the whole, every single object uses the same technique to find different solutions as done by other members of the group and creates their own separate environment. After all this, they combine their efforts and reach a single optimal solution by considering all required aspects. Technically, this process is a combination of many processes like exploration and search. In the exploration phase, they explore their environment within their range of reach and transmit the practical data to their neighbours by communicating with each other by means of various communication channels to decide whether the computed data is more feasible or not. In search In the search phase, they compare their observed data with the data they receive from their neighbours and prioritise the most cost-effective and promising data. They advance their path towards the most reliable direction. If the value of their neighbors' data is greater, it will move in that direction or else it will remain on its own path. After doing so, it will reset this and start the process again and again till they reach their defined goal. As we saw in this whole process during the selection of the most reliable and advantageous path, the agent can have those values which show that temporarily that agent becomes the leader of that virtual group, and it can be any other agent in each successive process. This kind of coordinating behaviour between various autonomous agents is the main philosophy behind swarm intelligence.

2.2 Particle Swarm Optimization

It is a well-known nature-inspired algorithm that is used to solve computationally hard problems. It is a population-based stochastic optimization technique that follows the concept of artificial intelligence as shown in Figure 2. below. It is inspired by the social behaviour of flocking birds and schooling fish. Here, the bird can be considered a particle, the group of them is a swarm, and optimization is the best use of the resource to solve problems. It was proposed in 1995 by Kennedy and Eberhart. In plain English, when a group of birds is flying and searching for food, every bird in the group shares their discovery with other birds as well, for the best exploration. Here, each and every bird helps to find the optimal solution, and this solution is heuristic because it is very difficult to prove the optimal global solution.

In Particle Swarm Optimization, the particles of the system update their velocity and position with respect to time and environment. The swarm must be able to carry out time and space computations. The swarm in the PSO should continuously find an optimal solution without limiting their movement and also keep their stable movement even during their changing movement mode to adapt to the change in the environment.

Particle Swarm Optimization can be of three types: Gradient PSO, Hybrid PSO, and Newton's method.

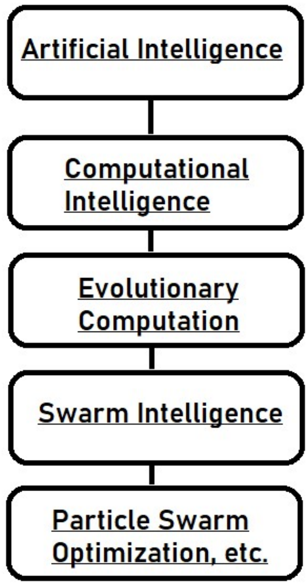

Figure 2. Particle Swarm Optimization Concept

2.3 Algorithm Fundamentals

Here we use the fitness function for optimization and the objective function is used to minimise or maximise the values that we are trying to optimize. The path generation algorithm works in a controlled manner, step-wise according to the required conditions as shown in Figure 3..

- We initialise the group of random particles and each particle finds its own optimal solution by iterating. In each iteration, every single particle gets updated by two best values, one is the fitness value, and the other is followed by the particle swarm optimizer.
- Every particle in the group updates its position and velocity.
- They store their records of the best results as pbest, or personal best, and gbest, or global best of any particle.
- And we can update the position by adding velocity to the older position of the particle.

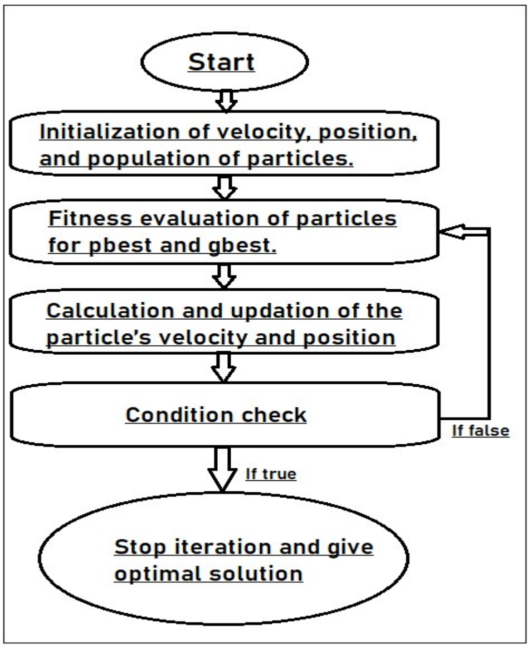

Figure 3. Flow chart of the path creation model of PSO

2.4 PSO Algorithm

2.4.1 Initialization

Initializing the population, position, and velocity of the particle as:

V_i: velocity of the particle.

X_i: position of the particle

2.4.2 Fitness Evaluation

The fitness value $F(x_i t)$ of every particle is evaluated, and if the value of fitness is better than the previous one, the updated value is (gbest).

2.4.3 Calculation and updation of the particle's velocity and position

- Velocity update of particles can be given as :

$$V_i t{+}1 = W.V_i t + c_l U_l t(Pb_l t - P_i t) + c_2 U_2 t(gbt - P_i t) \quad \text{.....[1]}$$

Here, in equation [1]

$W.V_i t$: This factor helps the particle to be in inertia, and search for new best solutions. At a higher value, this stage is termed "exploration" and "exploitation" at lower values. Here, W is the inertial weight positive constant.

$c_l U_l t(Pb_l t - P_i t)$: This factor is the Personal domination, $c_2 U_2 t(gbt - P_i t)$: This factor is the Social domination and On combining both the above it will be termed Intensification.

In social domination, interaction and movement toward the nearest most prominent neighbour can be studied with the help of three topologies: Star, Wheel, and Ring topology.

- Position update of the particles can be given as :

$$P_i t+1 = P_i t + v_i t+1 \quad \text{.....[2]}$$

2.4.4 Reiteration

In this step, the iteration is repeated or the repetition from step 2 goes on until the defined criteria are satisfied.

2.5 Research Gaps

There are numerous path planning algorithms available for implementation, but they do not always provide the optimal solution. There hasn't been a lot of research done on the use of nature-inspired and evolutionary algorithms. Nature-inspired algorithms are easy to parallelize and process concurrently, are devoid of derivatives, have few parameters, and are very efficient global search algorithms.

Chapter 3: Experiment And Result

3.1 Environment

The virtual environment is created with pre-defined static and dynamic obstacles for path planning as shown in Figure 4, where the desired number of tests are performed from which the most optimal solution can be carried out. Here, the environment consists of various obstacles such as circles, ellipses, etc. A test is also carried out where the goal, and position of the particle change with respect to time in a dynamic environment. The simulation is carried out in an IDE(Pycharm), where Python 3.9 is used to conduct the simulation, and the computer is used to perform with specifications Intel(R) Core(TM) i5-9300H CPU @ 2.40GHz, 8GB RAM, and 4GB(NVIDIA GeForce GTX 1050)Dedicated Graphic card.

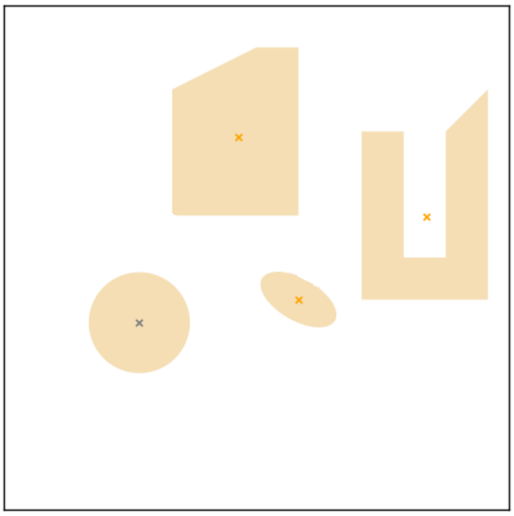

Figure 4. Pre defined environment.

3.2 Experiments

Three experiments are done, among which two of them are done to find the most optimal solution; many tests are done that give many path solutions, of which the most promising is selected; and in the third one, the simulation is done where the particle is continuously tracking its path towards its moving goal in a dynamic environment.

3.2.1 Experiment 1

In this experiment, the algorithm is tested various times to find enough solutions among which the best optimal solution is selected in an environment with static obstacles. Here, a total of five tests are done, among which the most optimal is selected with the least cost path length.

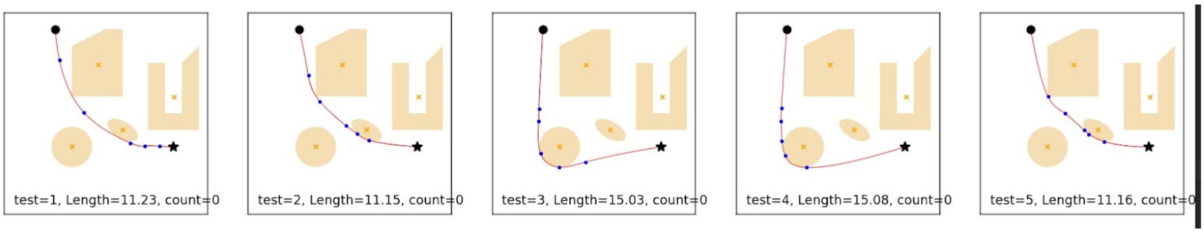

Figure 5. Static Environment path planning solutions

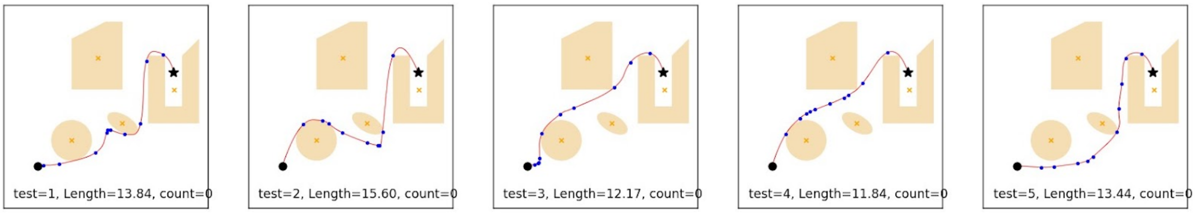

Figure 6. Static Environment path planning solutions with different goal coordinates

Here, we can see that from above, both the simulations, Test 2 in Figure 5. and Test 4 in Figure 6., are the best optimal solutions.

3.2.2 Experiment 2

In this experiment, the algorithm is tested to find the optimal solutions in a dynamic environment, and the goal is static. Here, the circle obstacle is dynamic, and the source is also moving towards the goal as shown in Figure 7.

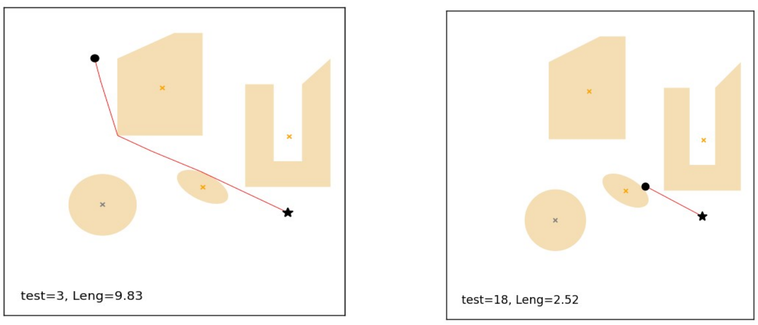

Figure 7. Dynamic Environment path planning solution with moving source and static goal.

In this simulation, a total of 23 best tests are performed for the simulation, with 5 spline internal points that are half of the variables, with a population of 100 and a total of 500 iterations. The velocities of the moving source and circular dynamic obstacle are 0.5 and 0.3.

3.2.3 Experiment 3

In this experiment, the algorithm is tested to simulate the solution in a dynamic environment with a moving goal, as shown in Figure 8.

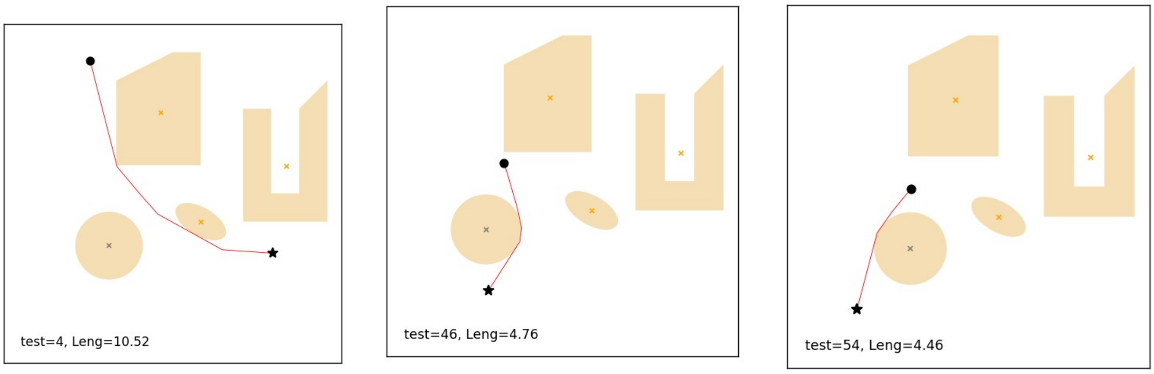

Figure 8. Dynamic Environment path planning solution with moving source and goal.

In this simulation, a total of 65 best tests are performed for the simulation, with 5 spline internal points that are half of the variables, with a population of 100, and a total of 500 iterations. The velocity of the moving goal, source, and circular dynamic obstacle is 0.15, 0.1, and 0.1.

Conclusion and Recommendations

We propose a nature-inspired path planning algorithm, Particle Swarm Optimization, by combining it with cubic spline interpolation for smooth curves. Because of its robustness and its usage in various different vast application environments, it has the capability essential for swarm optimization and the ability to find a collision-free path in a dynamic, complex environment. The results of experiments show us that even without having the proper knowledge of the environment, it has the ability to find a collision-free path during its journey. In the future, the work will be extended to include dealing with a more complex environment and learning and mastering the environment or the required situation during navigation and movement. The required work is also done to enhance its efficiency of velocity updation, position updation, and collision-free path generation in a more complex dynamic environment.

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Appendice

I am sincerely thankful to my faculty mentors. I am grateful to the guidance of **Dr. Saumil Maheshwari**, Assistant Professor, Information Technology, for his continued support and guidance throughout the project about how to implement such things. This project helped me a lot to know how the workflow goes on. Sir's published paper has also helped a lot to do this project. I am also very thankful to the faculty and staff of the department.

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