

Computer Games Development

Project Report

Year IV

Donal Howe

C00249662

[Date of Submission]

[Declaration form to be attached]

# Table of Contents

1. [Acknowledgements 2](#_Toc54714373)

2. [Project Abstract 2](#_Toc54714374)

3. [Project Introduction 2](#_Toc54714375)

4. Research Question…………………………………………………………………….

5. Objectives Involved ………………………………………………………………….

5.1 Technologies used ……………………………………………………………….

5.2 Steps to completion……………………………………………………………….

6. [Literature Review 2](#_Toc54714376)

6.1 Background ……………………………………………………………………….

6.2 Pathfinding ……………………………………………………………………….

6.3 Dstar Lite Search Pathfinding Algorithm ……………………………….……….

6.3.1 Overview ……………………………………………………………….

6.3.2 Key Information …………………………………………………………

6.3.3 Algorithm ……………………………………………………………….

6.4 AStar Search Pathfinding Algorithm ……………………………….…………...

6.4.1 Overview ……………………………………………………………….

6.4.2 Key Information …………………………………………………………

6.4.3 Algorithm ……………………………………………………………….

6.5 Lifelong Planning Astar Search Pathfinding Algorithm …………………………

6.5.1 Overview ……………………………………………………………….

6.5.2 Key Information …………………………………………………………

6.5.3 Algorithm ……………………………………………………………….

6.6 Dijkstras Search Pathfinding Algorithm ……………………………….……….

6.6.1 Overview ……………………………………………………………….

6.6.2 Key Information …………………………………………………………

6.6.3 Algorithm ……………………………………………………………….

6.7 Depth First Search Pathfinding Algorithm ……………………………….…….

6.7.1 Overview ……………………………………………………………….

6.7.2 Key Information …………………………………………………………

6.7.3 Algorithm ……………………………………………………………….

6.8 Jump Point Search Pathfinding Algorithm ……………………………….…….

6.8.1 Overview ……………………………………………………………….

6.8.2 Key Information …………………………………………………………

6.8.3 Algorithm ……………………………………………………………….

7.0 [Evaluation and Discussion 3](#_Toc54714377)

8.0 [Conclusions 3](#_Toc54714378)

9.0 [References 4](#_Toc54714379)

10.0 [Appendices 4](#_Toc54714380)

**List of Figures**

5-1 Dstar lite Path……………………………………………………………………………8.

5-2 Dstar Lite Algorithm ……………………………………………………………………9.

5-3 Dealing with underconsistancies ……………………………………………………..10.

5-4 Dealing with over consistencies………………………………………………………..10.

5-5 functor comparison ……………………………………………………………………..10.

5-6 How functor deals with ties ……………………………………………………………11.

5-7 Dealing with introduction of Untraversable …………………………………………...11.

5-8 Calculating a nodes key ………………………………………………………………..11.

5-9 Dstar Lite path on 2D grid ……………………………………………………………..12.

5-10 How Dstar Lite Path changes with wall on path ………………………………………12.

6-1 Astar Path ……………………………………………………………………………….14

6-2 Fcost functor …………………………………………………………………………15

6-3 Astar algorithm ………………………………………………………………………….16

7-1 Lpa\* Path ………………………………………………………………….

7-2 Lpa\* algorithm ………………………………………………………………….

7-3 The calculation of the key………………………………………………………………….

7-4 Lpa\* functor………………………………………………………………….

7-5 Lpa \* Path without Wall ………………………………………………………………….

7-6 Lpa \* Path with Walls ………………………………………………………………….

# 1.0 Acknowledgements

I would like to thank my project supervisor Oisin Crawley for his assistance on this research project throughout the year which is greatly appreciated.

# 2.0 Project Abstract

The idea behind my research project is to question when compared with the dynamic pathfinding algorithm known as “Dstar Lite” under a games development context will other heuristic and non-heuristic pathfinding algorithms be more beneficial when implemented into someone’s game or should they rather use one of the several different pathfinding algorithms which I have implemented into my own application, which contains the following algorithms : “Lifelong Planning Astar” which is an incremental heuristic version of the Astar pathfinding algorithm which allows for the replanning of the most optimal path without having to recalculate the entirety of the path, the “Astar search algorithm” itself, “Dijkstras search algorithm”, the “Depth First Search pathfinding algorithm” which is the only non-guided pathfinding algorithm in this application and the final pathfinding algorithm which is being compared inside of this paper being “Jump Point Search” which is a further extension on the Astar pathfinding algorithm and of course Dstar Lite itself being an incremental algorithm heuristic pathfinding algorithm which computes the shortest path from two given points on a grid and allows for the replanning of the given path without having to recalculate the path from start.

There is also the question on where these algorithms may or may not be applicable inside of different games as certain things may vary which include the following different edge weights(cost of travelling from cell to cell) the number of obstacles on a path and how they handle this and would it affect the time until the paths completion as well as the grids size which may not be the same across a game world and could vary depending on the type of game which is being made.

In this paper I will put forwards applicable data to each scenario and come to a conclusion whether the algorithms chosen when put against the Dstar Lite algorithm are a better alternative to the dynamic pathfinding algorithm or perhaps it may be the case where Dstar Lite is the more applicable algorithm for the scenario presented in the paper. Not only will the paper provide the times in which it took these algorithms to traverse these scenarios to find the shortest path it will also talk about the implementation itself and if the degree of difficulty which was involved in the implementation of each algorithm influences the decision of the user to implement the algorithm into their game. This will be discussed by giving pros and cons to the implementation of each algorithm. These algorithms will be given equal precedence when being compared to Dstar Lite and as such will be focused on equally so the reader can come to an informed decision on which algorithm that they want to implement.

# 3.0 Project Introduction

In computer games development, developers may be faced with a problem with how to get their character from point a to point b.When they are faced with this problem they may come to the decision to implement a pathfinding algorithm of their choosing which best suits their games environment and will safely get their character or game object from start to finish on a grid. This is a problem core to gaming. In their process to trying to find a solution to this problem they may potentially implement several different pathfinding algorithms onto their game world in order to try and find which one suited their game and its environment the best which could potentially be quite time inducive and what my research project hopes to achieve is to compare several of these different pathfinding algorithms on different scenarios’ so that the reader can come to a decision without having to do separate implementations. Where this problem becomes difficult to solve depends on what kind of grid they have implemented by this I don’t mean whether the grid is one dimensional or two dimensional by this statement I mean what size of grid they have chosen to implement, whether the world is changing dynamically and how this will affect the grid which in turn would affect the times it takes for these algorithms to complete and their memory usage will increase and how they handle these changes. This may for instance destroy a Cell on the grid by placing a wall or some sort of obstacle and as such they will have to change the course of their path for getting to the chosen end point safely and as quickly as possible. This is why I chose this topic by making comparisons between several heuristic and non-heuristic algorithms against Dstar Lite on a dynamic grid and how the data which I have collected as a result of my research may have an impact on developers and the games which they are developing due to the algorithms that they implement perhaps shine in different scenarios to others. It will do this as in my project I will allow a visual comparison between algorithms what I mean by this is that the user will be able to see the algorithm that they choose race against Dstar Lite in real time and the path which they take. So not only will they have a visual representation of the speed in which these algorithms work they will also have data displayed inside of this paper to back up the decision that they may eventually come to. My end goal of this research topic is to comprehensively and conclusively come to the most optimal decision for the reader of this project and then in turn they will be able to go and implement the algorithm most suited to their problem which will in turn optimise their games speed and alongside that be able to understand each algorithm in such detail that they won’t have any problem explaining it to others either and be able to implement it into their own game.

**4.0 Research Question**

The main purpose of this research is to find out which algorithm is best suited for traversing a dynamic 2D grid in a game world and find out their benefits and drawbacks. The algorithms which have been investigated for this project are the following “Dstar Lite” search algorithm, “Lifelong planning Astar”, “Jump Point Search”, “Dijkstras search algorithm”, and “Depth first Search” pathfinding algorithm.

**5.0 Objectives involved in the making of this project.**

**5.1 Technologies to be used:**

SFML -2.5.1

Visual Studio 2022

C++

**5.2 Steps to completion**

1 Setup a dynamic 2D grid

2 Implement Dstar Lite search algorithms in c++

3 Implement “Lifelong planning Astar” search algorithm in c++

4 Implement “Astar” pathfinding search algorithm in c++

5 Implement “Dijkstras pathfinding” search algorithm in c++

6 Implement “Depth first search” pathfinding algorithm in c++

7 Implement “Jump Point Search” pathfinding algorithm in c++.

8 Create test environment to gather data of each algorithm.

9 Record the results collected.

10 Make comparisons of each algorithm against Dstar Lite

# 6.0 Literature Review

**6.1 Background.**

This section of the paper presents a review on the pathfinding algorithms which have been implemented into the application. These concepts and understandings were needed to make a comprehensive and complete comparison of these algorithms on a 2D game world grid. These understandings allowed me to form a visual representation of the algorithms in the project.

**6.2 Pathfinding.**

There are several things needed to be understood when it comes to pathfinding algorithms in games development. First thing is why are these pathfinding algorithms done in the first place. These algorithms are done with the intention on getting an ai character or object in a game from point a to point b in a game world. What these algorithms do is generate a safe and shortest path along the grid world for the character to traverse. Which in turn makes the character movement more efficient than just manually moving them once they either hit into a wall or change their direction accordingly to where you want them to go. There are Two main types of pathfinding algorithms which someone will come across when researching the topic and they are directed and non-directed algorithms. What is the difference between the two? A non-directed pathfinding algorithm does not spend any resources on trying to figure out how far it is away from the end point given rather it is simply moving blindly until it finds its destination. A directed pathfinding algorithm does however spend resources on trying to figure out both how far it is away from the destination and the start. What they do is look around and access all the neighbouring nodes edge costs and will then move to the one with the lowest cost. One way which the lowest value path is calculated is using heuristics. What is a heuristic? A heuristic is used to affect an algorithms behaviour and guide them towards their chosen destination. it tells the algorithm an estimation of the cost of the distance of the node being evaluated from the destination node selected. There are several diverse ways to calculate the heuristic value of a node such as diagonal, Manhattan but the one used in the application developed and what has been Implemented into the algorithms which we are investigating inside of this paper is a form of heuristic which uses Euclidean distance. Which will be explained later.

That is a brief explanation of what a pathfinding algorithm is the several types and some of the feature which I have used as a part of my implementation. More key features which are needed for the readers understanding will be explained in more detail which is to follow.

# 6.3 Dstar Lite Search Pathfinding Algorithm

6.3.1 Overview

Dstar Lite is an incremental heuristic pathfinding search algorithm which allows for the replanning of the path after it has been found without the recalculation of the entire path. How does it do this? This is achieved by retaining information from the previous searches.

A picture containing text, crossword puzzle

Description automatically generated

Figure 5-1 Dstar Lite Path

6.3.2 Key Information

Key variables which need to be understood for the Dstar Lite algorithm. One thing to understand is that each node in the grid has these variables contained within them so each nodes values are separate to one another which in turn makes it easy for the priority queue to evaluate which node is to be expanded next.

“Gcost” – the Gcost of a Node is the distance from where that node is on the given graph/grid to the start node.

“Hcost” – the Hcost of a Node is the distance from where that node is on the graph/grid to the destination/goal node.

“Rhs cost” – rhs cost otherwise known as the right-hand side value is used with a different understanding in dstar lite to places found elsewhere in robotics. In the context of Dstar Lite one can think of it as an estimation cost to the start node whereas the Gcost is the actual cost to the start node. Keep that in mind for when I discuss this topic further.

“Key modifier”- key modifier found in the application as “K\_M” is used as an offset for when the start position of the robot or character moves along the path to prevent more skewed cost values further up the path. How this affects our calculation of a variables key will be further explained soon.

“a nodes key” – a nodes key is a pair or in the application is an std::pair that holds two values calculated in the calculate key function.

6.3.3 Algorithm

Text

Description automatically generated with medium confidence

Figure 5-2 Dstar Lite Algorithm

How does the algorithm work? Dstar Lite is an extension of Lifelong planning astar and is an incremental algorithm. Dstar rather than a typical search algorithm which searches from the star to the destination node, Dstar does not do this it searches backwards from the destination node to the goal node. Once a best path is found from destination to start the start position or where the robot is currently is moved to the next viable node closest to the destination node. This is where our key modifier value comes into play for instance when the heuristics are calculated initially based off the start node, the robot has now moved and in turn our start node has changed, so we must increase the value of our key modifier. This is why I explained it as an offset for the change in robot position otherwise after the robot has moved if our key modifier was not implemented into us calculate key function the nodes heuristic value would not be correct once a recalculation had to be made.

How is the shortest path found? we are dealing with two separate states of a node which are consistent and inconsistent nodes. What this means is a node is consistent it means that there are no current changes need to be made to it as its Gcost value and Rhs cost are equal in turn its values are consistent with one another. Then there is inconsistent which means that a nodes G cost values and Rhs values are not equal and as such we must deal with this to progress the search. Within this bracket of states there is two distinct types of inconsistencies. There is over consistency where our Gcost is Greater than our Rhs cost and there is under consistent where our Rhs values is greater than our Gcost value.

How do we deal with this? First thing is to make a check for over consistencies and once that is done we need to relax our Gcost value down to our Rhs value similar to what is done in Dijkstra’s Search algorithm once that is done we search the neighbours of the current node and assign the smallest Rhs value of our neighbours to our current node and readd the node to back into our priority queue.

Text

Description automatically generated

Figure 5-3 Dealing with over consistencies.

In the case of underconsistancies we need to assign our rhs value to infinity and update the node. The same thing is done where the rhs is calculated to and is returned into the queue with the updated value.

Text

Description automatically generated

Figure 5-4 Dealing with underconsistancies.

However inside of the updating vertex function we need to check if that node is not already in the queue as to ensure we don’t put that node into the queue if it is already there. With this information you can understand that the goal is to make nodes consistent with itself and won’t be revaluated if the node is consistent.

How is the queue ordered? The queue is ordered using a functor which will return the node with the lowest cost. It does this by comparing a nodes key against the next node in the queue once it needs to be reordered.



Figure 5-5 functor comparison

What about in the case of nodes with equal values or a draw? The functor returns the node which is higher in the priority queue.

 Figure 5-6 Dealing with ties.

Once the best path is calculated how do we deal with changes? Dstar holds onto the path calculated on the earlier search and in turn uses this to update the path quickly as it does not need to recalculate the entirety of the path. What the algorithm does is it checks for any changes in the neighbours of the current robot position and if one of those nodes have increased edge costs and are as such now not able to be traversed, we will recompute a best search around the node.

Text

Description automatically generated

Figure 5-7 Dealing with introduction of untraversable.

How to calculate the key of a node? To calculate the key of a node you do as such the first of the pair is the minimum value of the Rhs cost and the Gcost of the node plus the key modifier plus the heuristic value of that node. The second of the pair is the minimum of the Rhs value and Gcost value.

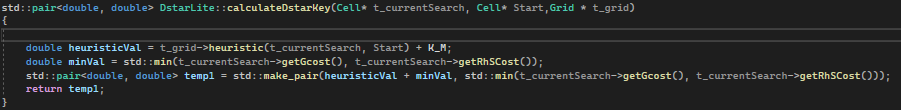


Figure 5-8 Calculating a node key.

With the individual aspects of Dstar Lite having been explained above the next question that needs to be asked is how does it behave? Dstar Lite behaves like what Dstar behaves with the exception that it is not as complicated to implement and does not have the same memory usage hence why it is coined Dstar Lite. When the path is initially calculated Dstar Lite acts like a greedy first search and what this means is that it takes the lowest costing node to the start node as remember Dstar Lite searches backwards from the destination node to the start node. One thing to note is that in an 8 directional graph where there is no extra cost for diagonal movement will lead to a zig zag pattern of movement for example:



Figure 5-9 Dstar Lite Path on 2D Grid

To prevent this sort of movement one can simply add an added weighting to move diagonally. However, in my implementation this is not done as I did not want this. Next thing to take note is how the algorithm acts once a node along the path becomes untraversable with a wall on the path. One can note how the wall has Gcost and Rhs cost of infinity.

Calendar

Description automatically generated with medium confidence

Figure 5-10 How Dstar Path changes with wall on path

That is an overview of the Dstar Lite algorithm and how it works on a 2D dynamic grid aswell as how it behaves when a wall is placed on the given path

**6.4 Astar Search Pathfinding Algorithm.**

6.4.1 Overview

Astar is a non-incremental heuristic search algorithm which means that is solves the traversing problem from scratch and that it knows the end and start point. It then tries to find the shortest path to the end point; However it will rerun itself if an obstacle gets in the way. Astar can find the shortest path through a priority queue which will compare the values of each node using both their Hcost( distance from the node) and Gcost( distance from the start node). This is how it knows to look at certain nodes first. Astar unlike Dstar Lite does not retain any information from search to search. Astar is a very widely used pathfinding algorithm in the games development industry.

A picture containing shoji, crossword puzzle

Description automatically generated

Figure 6-1 Astar Path

6.4.2 Key Information

When understanding how the Astar pathfinding algorithm works one must first understand some key features which is used inside of Astar. Note the calculating of a nodes heuristic value is the same as in Dstar Lite there is not any additional costs for moving diagonally as previously mentioned one could be easily implemented.

“Fcost” – in Astar the Fcost is the value of the Gcost ( mentioned in 6.3.2) plus the value of the Hcost (mentioned in 6.3.2). what this value does is allow us to easily investigate a certain node based on its location in the grid.

“Gcost” – (mentioned in 6.3.2)

“Hcost” – (mentioned in 6.3.2)

“weight” – weight is the cost it takes to move to a node. If you want to place a wall on the grid you can change the node which the wall resides in have a weight of infinity so that node will never be investigated.

“Previous pointer” - this is for constructing the path. This can also be known as the parent node of a given node and is used to reconstruct the path once it is known.

“Heuristic” – despite it being calculated in the same way as Dstar lite as mentioned above we must note how the heuristic can greatly affect the efficiency and behaviour of our Astar algorithm. If the heuristic is less than the cost of moving to the goal then it will always find the shortest path” If h(n) is always lower than (or equal to) the cost of moving from n to the goal, then A\* is guaranteed to find a shortest path. The lower h(n) is, the more node A\* expands, making it slower.” **(Patel, 2019)**,but if it is greater than the cost of moving to the goal then it may not find the shortest path “If h(n) is sometimes greater than the cost of moving from n to the goal, then A\* is not guaranteed to find a shortest path, but it can run faster.” **(Patel, 2019)**, as you can tell depending on how we write our heuristic you could potentially skew the time or path given back to us by Astar and as we want the fastest time possible and best path possible this is important to be sure about.

Note how Astar does not have an Rhs cost this is due to it not being an incremental algorithm and does not need to retain any information instead it completely recalculates the path.

6.4.3 Algorithm

The Astar algorithm works as such first thing you need to initialize all of the nodes inside of your grids values. Calculate their Hcost distance from the goal node as well as setting their gcost to infinity. Set their parent Cell to be a null pointer as this will be assigned later in the function. Next you need to establish a priority queue which takes a functor that will compare the fcosts of a node to one another or just what their fcost value would be.

Text

Description automatically generated with medium confidence

Figure 6-2 Fcost functor

Once this has been done you need to insert the start cell into the priority queue and set its   
Gcost to 0 and it to have been marked/visited and search all of their neighbours( it will go in order of the lowest Fcost value due to the functor). If the node is not equal to its parent it will check to see if the distance to the child( child cell/ current cell’s Gcost + the weight it takes to move there) is less than the Gcost of the child. Then you will set that current node parent to be the top of the priority queue and its Gcost to be the cell at the top of the priority queue’s Gcost + its weight. Then if the current node which you are searching through is the goal node terminate the search. Otherwise if this is not the case and the nodes weighting and Gcost is not less than the child’s Gcost then simply set that current cell as marked and pus it to the queue. If the current cell runs out of neighbours to be searched remove it from the queue when done the algorithm should look like the figure below(figure 6-3 Astar algorithm)

Text

Description automatically generated

Figure 6-3 Astar algorithm

This is an overall view of the Astar search algorithm and all of the key information in which you need to know before I can correctly display my findings and make comparisons between Astar and Dstar Lite

**6.5 Lifelong planning Astar Search Pathfinding Algorithm.**

6.5.1 Overview

Lifelong planning Astar is an incremental heuristic pathfinding algorithm that finds the path by updating the values of nodes from previous searches rather than recalculating the entire graph and having to start from nothing it is one step down from Dstar Lite which is a continuation of the lifelong planning astar algorithm. The algorithm uses the heuristic function to guide itself towards the goal node. Unlike dstar lite lifelong planning astar searched from the start node to the goal node. When dealing with changes to the grid it re-expands nodes from previous searches which have been affected by the change and their predecessors to replan the path

A picture containing graphical user interface

Description automatically generated

Figure 7-1 Lpa\* Path

6.5.2 Key Information

In order to get a better understanding of lifelong planning astar one must first understand the key information which I am about to explain to you

“Closed List” – this is a list of nodes which have already been expanded by the algorithm.

“Open List” – this is the priority of nodes which is currently being expanded by the algorithm.

“Rhs cost” – as mentioned in (6.3.2)

“Gcost” – as mentioned in (6.3.2)

“Key Value” – as mentioned in (6.3.2), the key value is calculated the same way to Dstar Lite with the exception there is no key modifier involved with the calculation.

“Start Node” – this is the start node of the algorithm, i.e. where it starts.

“Goal Node” – this is the goal or destination node i.e. where you want to get to.

That is all of the key variable information which you need to understand the functionality of Lifelong planning Astar.

6.5.3 Algorithm

Text

Description automatically generated with medium confidence

Figure 7-2 Lpa\* Algorithm

The calculation of the key In Lpa\* works as such, it is an std::pair and the first of the pair is the minimum cost between the Gcost and the Rhs cost + the heuristic value from the goal node. The second of the pair is the minimum of the G cost and the Rhs cost.

Text

Description automatically generated

Figure 7-3 The calculation of the key

While the open list which has been populated with the start node is note empty.

Remove the node with the smallest key values which is compared via the functor as such. The functor corrects tie values in the priority queue by returning the node highest in the queue already.Text

Description automatically generated

Figure 7-4 Lpa\* functor

If the node is over consistent as explained in (Figure 5-3) relax it down to its rhs value and add all of the neighbours of that node to the open list. If the node is under consistent as explained in (Figure 5-4) update that nodes g cost to infinity and add that nodes neighbours to the open list. If the node has already been expanded terminate the current search. If this is not the case update the nodes rhs value and add it to the closed list. For each node that is in the closed list and its neighbours we want to update their rhs values if they go through nodes which are in the process of being expanded. Then lastly for each node in the open list we want to expand each of their neighbours and update their key values with the new rhs cost and g cost. As the way to deal with nodes being both over and under consistent having been already explained in the explanation of how Dstar Lite works it will not be replicated here. However it is the same way of dealing with them in this case.

A picture containing shoji, crossword puzzle, building

Description automatically generated A picture containing shoji, crossword puzzle

Description automatically generated

Figure 7-5 Lpa \* Path without Wall Figure 7-6 Lpa \* Path with Walls

**6.6 Dijkstras Search Pathfinding Algorithm**

6.6.1 Overview

Dijkstras search algorithm is a guided search algorithm that uses node weights and connections to find the shortest path to the goal node. Whereas Astar uses the heuristic value distance from the goal node as hcost and distance from the start node Gcost to find the path, Dijkstras only uses the distance from the start node of each node to find compute the shortest path.

6.6.2 Key Information

6.6.3 Algorithm

**6.7 Depth first Search Pathfinding Algorithm**

6.7.1 Overview

Depth first search is an example of a non- heuristic guided search algorithm, it starts at the root of the graph in the case of this project being the start node which you select. It then traverses through the graph using the neighbours so eventually find the goal. It is not guided it simply goes as far as it can give a specific direction chosen.

6.7.2 Key Information

6.7.3 Algorithm

**6.8 Jump point search Pathfinding Algorithm**

6.8.1 Overview

6.8.2 Key Information

6.8.3 Algorithm

# 7.0 Evaluation and Discussion

Replace this text with Results and Discussion.

Describe the results using diagrams such as graphs etc. as appropriate and discuss what the results mean.

Example: Results indicate that once the threshold gets over a certain point it significantly reduces player performance and player experience

**8.0 Project Milestones**

Replace this text with Project Milestones.

Key project milestone dates and measurement on schedule, was project schedule adhered to, effectively planned for delivery on-time or ahead of schedule if appropriate.

**9.0 Major Technical Achievements**

What are your major technical achievements?

**10.0 Project Review**

What went right? What went wrong? What (if anything) is still outstanding/missing (i.e., still left to do)? If starting again, how would you approach this project differently? What advice would you have for someone attempting a similar project in the future? Were your technology choices the right or wrong ones? If you chose the wrong technology, provide justifications for why you think this. What were the implications of your technology choices?

# 

# 11.0 Conclusions

summarise your work and findings.

**12.0 Future Work**

Indicate what might be some next steps to try (if a student next year was going to undertake a project in this area what might be an interesting thing for him/her to examine?).

**13.0 References**

<https://core.ac.uk/download/pdf/235050716.pdf> - Path Planning Algorithm using D\* Heuristic Method Based on PSO in Dynamic Environment Firas A. Raheema \*, Umniah I. Hameedb

<https://medium.com/@nicholas.w.swift/easy-a-star-pathfinding-7e6689c7f7b2> -Nicholas Swift Feb 27 2017

<http://www.cs.cmu.edu/~ggordon/likhachev-etal.anytime-dstar.pdf> - Maxim Likhachev† , Dave Ferguson† , Geoff Gordon† , Anthony Stentz† , and Sebastian Thrun‡

<https://www.ri.cmu.edu/pub_files/pub3/stentz_anthony__tony__1994_2/stentz_anthony__tony__1994_2.pdf> -Anthony Stentz

Koenig, S. and Likhachev, M. (n.d.). *D\* Lite*. [online] Available at: http://idm- lab.org/bib/abstracts/papers/aaai02b.pdf

encyclopedia.pub. (n.d.). *Jump Point Search Algorithm*. [online] Available at: <https://encyclopedia.pub/entry/24246>

# Patel, A. (2019). *Heuristics*. [online] Stanford.edu. Available at: <http://theory.stanford.edu/~amitp/GameProgramming/Heuristics.html.>

# 14.0 Appendices

Replace this text with Appendices.

This might include ethics application and other relevant material e.g. copy of any questionnaires used.