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Using Modern Mapping and Graph techniques to locate missing persons quickly.

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# Chapter 1: Abstract

The subject of this report is going to concern the use of modern data analysis and gathering techniques and to investigate how these techniques may be used to improve and enhance search and rescue operations going forward. The traditional method involves sending out search parties, which could be dangerous and costly depending on the circumstances of any given operation.

Weather, geographical change and daylight are just a few of the factors that influence how dangerous any given operation may play out. Over time, realising the increasing importance of human value, it has become necessary to reduce the risk associated with sending humans to perform these arduous, difficult tasks.

Modern technology such as drones, and mapping techniques could be combined to create a better and less costly solution that improves both the time taken to carry out these operations, and reduce the associated human cost that goes with such operations.

# Chapter 2: Introduction

\*REWRITE\*

Save this one until last. In basic terms, the purpose of this project is to see how existing technologies can enhance search and rescue missions using a combination of technologies, such as satellite navigation and pathfinding algorithms. In simple terms, this project will use algorithms like Dijkstras, Depth first search and Breadth first search to determine a set of possible routes and priorities in which to search these routes. The main challenge here would be setting these techniques to work over a volatile 3d space, unlike conventional satellite navigation systems, which only deal in 2d areas. Another challenge associated with this would be that there is no single destination or optimal route to reach them. You also have to factor in the number of people in a search party. More people can search more ground at once, multiple people can reach multiple destinations at the same time. This would mean that the route would have to implement multiple routes based on the manpower at their disposal.

This project will have to focus on the possible technologies that could be used to map a 3d space in a cost efficient and effective manner. This field breaks down into various different classes of technology, such as Lidar and Photogrammetry.

The project will seek how best to implement this information and techniques into search and rescue missions and general location services.

Graph theory will then be used to traverse the finished product, and research will be conducted into optimising a possible route or set of routes to try to divide a search parties resources and manpower along a single or multiple routes.

## Chapter 2.1 Research Questions

The purpose of the research is to determine what kind of technology would be best suited to the task of mountain rescue location, and how that technology may be applied.

## Chapter 2.2 Research Objective

The objective of the research undertaken for this project is to see if modern navigation techniques and tools can enhance search and rescue operations. The topic will take a deep dive into traditional techniques, such as graph algorithms and GPS techniques, and how these techniques may be implemented into a modern application.

# Chapter 3: Literature Review

## 3.1 Search and Rescue

Search and Rescue is a term that refers to the location of people to be considered missing in areas of hazardous environments. The process of Search and Rescue generally involves sending a search party out to the general location of the missing party and dividing manpower out into smaller parties and deciding to divide out the search area into more manageable sections.

The first major advantage in the field of search and rescue was the use of dogs to locate people. Dogs have a heightened sense of smell with significantly more smell receptors than humans (Agata Kokocińska-Kusiak, 2021).

In modern times, this process takes advantage of numerous advanced technologies such as drones and helicopters to aid in the discovery of potential victims. Due to the increasing technology in recent years, the manufacturing of certain types of helicopters and drones specifically for the purpose of search and rescue, such as the S-70i – Search and Rescue Helicopter. The process of using drones has gained massive popularity in recent years, as it is a safer option than sending helicopters or people to check for the presence of the subject, due to it not being necessary to send living beings to do the work. These drones often come equipped with thermal imaging cameras to further speed up the process, such as the DJI M300RTK.

## 3.2 Terminology Relating to Missing People

The terminology associated with missing people is an area that needs advancement. There are not many terms associated with missing people that work functionally. There is no shorthand for a missing person, they just have to be called “Missing Person” or “subject”, or any other suitable word that just applies to someone who may be missing.

The problem with the lack of terminology in relation to missing persons is that time needs to be spent unnecessarily on defining terms each time an instance of missing people happens. Situations need to be described in more detail for each circumstance, and adds time to the investigation process, as

This means that any attempt to search on the subject is unnecessarily hindered by a lack of search terms that relate to specific circumstances and any attempt at really taking advantage of modern technologies in the acquisition of missing people is hindered by bureaucracy and red tape, as all these circumstances have to be described in greater detail than initially anticipated. More work in this area is needed.

## 3.3 Defining Search Areas

Typically, on a global scale, the world is divided into different regions where bodies are responsible for defining the areas under the authority of each organisation. This is a primary division of search areas. There exist 13 main areas of consideration under the SAR.

When an area needs to be searched, the area needs to be assessed where the approximate location of the missing person needs to be gathered. The process of dividing a search area falls under the jurisdiction of two United Nations organizations, the International Maritime Organization(IMO) for sea search and rescue missions, and the International Civil Aviation Organization(ICAO) for ariel missions.

This process is initially done by defining the main area that someone may have gone missing. This is accomplished using mapping techniques. Then, the area is broken down into smaller, more manageable sub-sections that are more easily searched.

In Ireland for sea search and rescue operations, the Irish Coast Guard is responsible for abiding by the guidelines set out by the National Search and Rescue Plan, and they have bases in Dublin, Valentia Island and Malin Head. (Gov.ie, 2019)

For ground based Search and Rescue operations, the National Search and Rescue Plan does not clearly define who is responsible, alluding to An Garda Siochana having a duty to safety. It states that: “There are no international conventions governing land search and rescue. However, legislation governing policing activity places an obligation on An Garda Síochána to protect life and property, and the provision of land SAR services derives from this requirement” (Gov.ie, 2019).

## 3.4 Researching and Defining a Sample Area

The area in the surrounding where this report was written is mainly mountainous and has jagged, rough terrain. This terrain is naturally difficult to design infrastructure around and to navigate correctly. In the year 2022, a hiker named John Dunne went missing around the mountain of Carrauntoohil, Co. Kerry (Irish Examiner, 2022).

The article describes Mr. Dunne as an experienced walker. Cases like the one of Mr. Dunne demonstrate the need for advanced search and rescue techniques.

The area this project is going to focus on is Carrauntoohil. The mountain, located in the MacGillycuddy Reeks Mountain range, is a formidable area that presents a variety of challenges in the terrain and areas to be assessed. There are lots of jagged rocks, steep inclines and other hazards that may need to be mapped and accounted for when deciding what areas to assess and what kind of weighting may need to be applied in which given circumstance. (Kerry Mountain Rescue, N/A).

## 3.5 Investigating Navigation Techniques

Modern technology can be used to improve the efforts of search and Rescue services by making parties more efficient and reducing the elements of human liability that are inherent to old fashioned techniques. Using people to do this requires a high amount of human capital to be invested, as the people involved are required to be strong and fit enough to be able to access the areas someone may get lost in.

The obvious solution to this problem is to use forms of technology as a substitute for this human capital. The use of tech such as drones allows humans, and by extension, associated liabilities to be limited. This section is going to detail some of that technology.

### 3.5.1 Pathfinding in 3D Environments

In 3D spaces, the options for pathfinding are steadily improving, as the objective of 3D spaces are naturally more complex than in a 2D environment. Therefore, the challenges need to be met appropriately with the correct mix of modern technology and their applications. For 2D applications, Graph theory and the A\* algorithm can be used to ascertain the shortest path between two points (Alex Nash, 2010). For 3D spaces, the process of pathfinding becomes more complicated, requiring different algorithms to gather the shortest path.

The A\* algorithm doesn’t work as effectively over 3D spaces, as it was primarily designed to work over 2D spaces, and doesn’t effectively work over the same space if converted to utilise the third dimension.

### 3.5.2 Global Positioning System

The term Global Positioning System(GPS) refers to any system that sends broadcast navigation pulses to users on earth (Logsdon, 2022). It is a useful system for locating and guiding a given device with the necessary information to make informed decisions as to how to get from one location to another. These systems are then work with different pathfinding algorithms to reach different points for different purposes. For example, Shortest Path First would allow the user to demonstrate a path that takes the least distance between two points. Whereas something like the A\* algorithm that would take a weighted approach to solving the least costly method of reaching a given point.

The first instance of Global Positioning System was in the era of the Sputnik satellite in 1957, when scientists discovered that they could track satellites using shifts in their radio signals. This uses the principal that any receiving device could determine its position based on the strength of the signal. (Aerospace, 2024)

### 3.5.3 Graphs and Corresponding Algorithms

In computing, graphs are an abstract data type that connect nodes(vertices) via edges. Graphs come in many different forms such as directed or undirected and weighted or non-weighted. Graphs are commonly used in Social Networks to determine which users are likely to know each other based on mutual contacts, and weighted graphs are commonly used in mapping projects as they provide a weighting between vertices to make their calculations (Thomas H. Cormen, 2009) P589.

Pathfinding algorithms will have to be implemented into the project to decide how to navigate over a search area. There exists a multitude of algorithms to use for this purpose. Dijkstra's algorithm, Breadth first and Depth First will all receive consideration in factoring in which is the likely way to reach people first from a given location. There are promising results posted from studies involving these algorithms (Pajaziti Arbnor, 2024). The main area to consider researching here is how existing navigation systems utilise these algorithms and use a similar system for this report.

The type of graph used by this project should depend on the type of pathfinding that needs to be done. The terrain of mountains provides a unique challenge in that it provides a third dimension to the proceedings. This will impact pathfinding such that the differences in elevation have to be accounted for more so than if one were to design a standard pathfinding system, such as satellite navigation.

## 3.6 Methods of Assessing Physical Terrain

As time goes on, the options available in terms of assessing geographical data become more varied and more impressive. Even the public now has access to technology such as Unmanned Arial Vehicles (Drones) that allow the user to assess any number of objects or terrain of their choosing. At a wide range of technologies and prices, these options need to be carefully considered for their purpose so that the objective is achieved in the most reasonable manner possible. This section aims to detail some of those technologies to decide the correct tool for the job. (Liyang Xiong, 2022)

### 3.6.1 Photogrammetry

Photogrammetry is the process of using various techniques and formulas on photos to assess a physical object and gather measurements from them (3DSourced, 2023). When these areas are considered, the user should then be able to map a 3D space and plan out a route according to graph algorithms.

Photogrammetry breaks down into multiple smaller techniques based on the angle of photo that is taken. If using vertically taken photos, the horizontal axis is pronounced and if using oblique photogrammetry, the vertical axis makes itself more pronounced.

### 3.6.2 Google Elevation API

Google hosts an API for returning the elevation of any point that is indexed on one of their maps. This information could prove to be useful in assessing the surrounding terrain and provide information to incorporate into the pathfinding route. The API receives an input of longitude and latitude, and returns an elevation to the user at the given coordinates. This returns either a JSON or an XML response in Meters. It should be noted that this a paid API, although usage can be forcibly limited. It must be used sparingly, or a free solution could be found. (Google, 2024) This report is going to assume the use of Googles Elevation API, and a return type of JSON.

If the bounding box for the project was to be extended to a more serviceable range, a range of 5 metres per box section, the project would be rendered prohibitively expensive. This would produce 160,801 different requests to the Google Maps API, at a cost of 4 cents each as it falls within the second category. This would produce a total number of $643.20 Dollars. For the purposes of this report, that would be considered prohibitively expensive.

This leaves the project with two options, using an alternative to Google Maps Elevation and using the bounding box with more divisions, which would be more accurate but expensive, or using a bounding box with less divisions, therefore, accuracy would suffer as a result, but would be cheaper to make.

### 3.6.3 Alternatives To Google Elevation API

Looking at the market alternatives to Google Elevation API, the candidates on offer generally fall into two categories, prohibitively expensive, or prohibitively slow. In practice, this application needs data quickly, as missing people generally need to be found fast. Studies show that people quickly perish under the circumstances of mountain terrain.

### 3.6.4 Carrauntoohil

Carrauntoohil is a part of the MacGillycuddy Reeks Mountain Range, in Co. Kerry, Ireland. It is Irelands highest summit and is considered a formidable challenge for experienced hikers. It is often the source of Search and Rescue, as it is a huge area with lots of potential for getting lost in. The mountain range mainly consists of red sandstone. This means that the geology of the area is treacherous and hard ground.

The summit of Carrauntoohil is located at the following co-ordinates: Lat: 51.99904, Long: -9.74324 (Views, 2024). The task here should be to manufacture a bounding box around this area and calculate the elevation based on the latitude and longitude of the selected point. A bounding box could be broken into several different points to create a 3d space from the given co-ordinates.

This report is going to use the summit of Carrauntoohil as a base point for its pathfinding purposes, as this provides a tall summit and an area of much concern for hikers and Search and Rescue teams alike.

## 3.7 Hardware and Technology

### 3.7.1 Python

The Python Programming Language is a high-level, general purpose, object-oriented programming language that is easy to use and excels at a wide range of things (Python.org, 2022). It can be used for GUI programming, embedded systems and web development and everything in between, as it hosts a wide number of libraries and frameworks for any such purpose. It is easily run on command lines, used through scripts and Notebook type applications, such as Jupyter or Googles Co-Lab service.

It is a language with a considerable skill curve and is used by beginners and experts alike. Being an interpreted language, it is easy to work with, but possibly slower given that the code cannot be pre-compiled. Although it makes up for being slow computationally by being more concise, less verbose and faster to develop with, making it an ideal choice for applications that need to be developed quickly.

### 3.7.2 NumPy

NumPy is an open source maths library for the Python programming language. NumPy adds functionality over the base mathematical functions available as part of the main Python package. NumPy is short for NUMerical PYthon and it contains several advanced methods of working with arrays, fourier transformation and linear algebra.

The NumPy library is faster operationally when used on computations than its contemporary libraries and competition because it uses vectors and parallel processing on a C implementation of arrays to process them up to 50 times faster than standard libraries. (NumPy, 2024)

### 3.7.3 A\* Algorithm

The A\* Algorithm is an Any-Angle pathfinding algorithm that tends towards finding the shortest path between two points. A\* is regarded as a smart algorithm that uses many factors such as weighting to decide which direction to prioritise in its quest to efficiently find the shortest path between nodes.

The algorithm works by assigning a weighting to different points and how these groups of weightings impact the ability to reach different nodes. Where multiple choices of nodes are available, the algorithm picks the lowest cost estimate of travel itinerary. (Cox, 2024)

In the case of search and rescue, this or similar algorithms could be used to design an effective route to a destination from a source given all the factors involved, as with the suggested terrain for this project, a weighting will have to be applied.

In depth, the algorithm works by

### 3.7.4 Lazy Theta\* Algorithm

The Lazy Theta\* Algorithm is an algorithm that improves on the A\* algorithm in numerous ways. It is considered an optimised form of the A\* Algorithm and improves the formula by using less line of sight checks. Different algorithms suit different purposes, and the Lazy Theta\* algorithm has

# Chapter 4 Methodology

The research above would help to design and implement a suitable system for the purposes of locating people who went missing on mountains.

## 4.1 Gathering Necessary Data

For the purposes of this report, the data on a selected search area will have to be acquired. The data will involve collecting the Latitudes, Longitudes and Elevations of any given search area. The terrain will then have to be assessed and the appropriate routes and areas gathered.

### 4.1.1 Acquiring Elevation of Selected Search Area

The surrounding area has coordinates that can easily be gathered by using Google Maps and recording the distance away from the summit the search area will have to be defined. When these coordinates are gathered, a bounding box can be created. The bounding box will have minimum and maximum values for longitude and latitude, and these coordinates will be sent to the Google Elevation API to determine the elevation at each individual coordinate.

The area can be broken down by determining the difference between each set of coordinates of the bounding box. This difference can be divided however many times the user requires. For the purposes of designing a sensible search area, a balance must be struck between detail and usability. A very small search area would be far easier to design a set of coordinates for because it should divide into manageable sections very easily due to a reduced number of API calls to Elevation API at the cost of making the search area too small. A very large search area would be prohibitively expensive as it would have to be broken down into many more sets of coordinates.

For the purposes of this report, a search area of 2 kilometres will provide a compromise between detail and usage. This 2km squared search area will then have to be broken down into a smaller grid for use in mapping across three dimensions. If broken down into 100 boxes of 100m2 , the area should be a combination of manageable and detailed, while the calculations should not be prohibitively expensive, hitting the Elevation API 441 times. This falls below Googles maximum number of requests per use, and can be run all at once. If the box was broken down into smaller boxes requiring more points, the API would have to sleep to prevent the API from timing out.

The bounding box has a minimum latitude of 51.99045 and a maximum latitude of 52.00844.

The bounding box has a minimum longitude of -9.7573 and a maximum longitude of -9.728086.

The distance between each of the latitudes and longitudes for coordinates is 2 kilometres, giving a 1 kilometre search area around the summit. With this information, the user should be able to use maths to gather a set of points that correspond to points in the bounding box to break areas down in terms of geographical importance. A suitable algorithm is shown below, implemented in the Python programming language, with the API key removed for security purposes, and a sample output is shown in the screenshot below. A screen shot of a computer

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This method returns the elevation at each point that is entered. It is run through a loop, for each of the steps given. The JSON needs to be parsed from the returned request, and it is accessed at various points using the JSON library to access it. The elevation, Latitude and Longitude are all accessed and returned from where they were located in the response.

The sets of Longitude and Latitude were then exported to an excel Comma Separated Values(.csv) file for manipulation later.

### 4.1.2 Displaying Plots

When it comes to working with 3D spaces, Python has various libraries available to assist a user with that task. The data can be viewed using a plot from MatPlotLib. The data needs to be extracted from the CSV file from the previous step. This is accomplished using the Pandas library, as it has methods available for reading values from these files, in the form of a DataFrame. The values for Latitude, Longitude and Elevation can then be determined and inserted into a suitable MatPlotLib figure for displaying the data.

# Chapter 5 Design

## 5.1 Design Justification

The report will need use cases to ascertain viability for the project in the form of user stories. In cases where people go missing, there is an imperative related to finding the person quickly. In this regard, the program needs justification. For this reason, the following user stories can be implemented with the program.

Epic, User Stories, Acceptance Criteria, Priority, Description.

## 5.2 Prototype

Then, a prototype is required to demonstrate basic functionality of the application. The prototype is not going to be functional, and will just be used for the purposes of conveying a specific design.

# Chapter X Conclusions

In conclusion, the success or failure of this project ultimately hinges around the cost of the technology involved in implementing the project. In the case of mountain rescue, this project would be prohibitively expensive to implement over the course of a mountain range. The area would only have to be mapped once in real world applications, although the area can be subject to change due to weather variations and unforeseen events that may fundamentally change the environment.

For the purposes of locating possible victims, the project does work as intended. It has successfully mapped out routes in accordance with the graphs and data given.

# Addendum - Glossary

This section contains some commonly used terms and concepts with regards to this report.

API – Application Programming Interface – Describes how parts of a computer program interact with each other.

SAR – Search And Rescue – Term describing search and rescue operations.

GPS – Global Positioning System – Satellite system for gathering coordinate values.

Lidar – LIght Detection And Ranging – Laser technology used to gather distances.

IMO – International Maritime Organization.

ICAO – International Civil Aviation Organization.

UAV – Unmanned Ariel Vehicle, otherwise known as a drone.

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