AALBORG UNIVERSITY
STUDENT REPORT

ED1 - P2 - H103

Unknown terrain mapping and navigation

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STUDENT REPORT

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Preface

From hereby on, every mention of 'we' refers to the five co-authors listed below.

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Chapter 1

Introduction

We started out the project with a brainstorming session where we discussed different problems we would like to solve. By the end of the session, we came up with the following list of problems:

- Noise pollution
- Navigation using echolocation
- Re-usability of heat waste
- Mapping unknown terrains without any external technologies
- Maze navigation

We could identify a common theme amongst these problems, which led us to the conclusion that the problem domain should be within mapping and navigations.

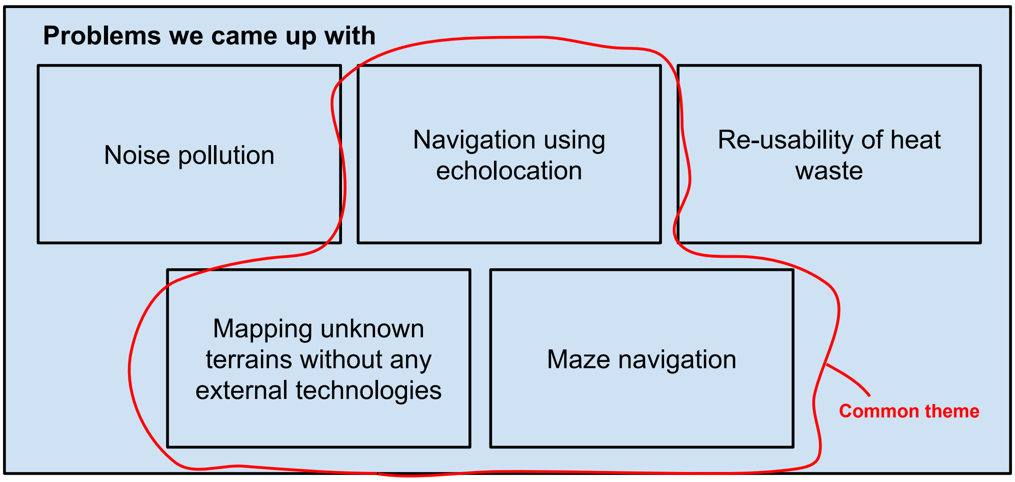

Figure 1.1: High level block diagram expanding upon our brainstorming session

Furthermore we decided to cut down and expand upon the problem-domain we set for ourselves. This led to more discussions on possible outcomes, uses and benefits of such system.

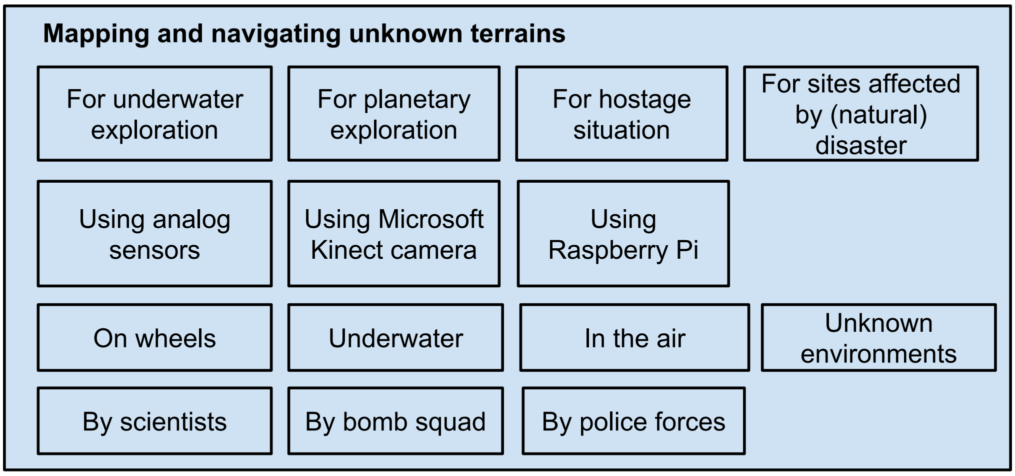

Figure 1.2: Low level block diagram expanding upon the common theme we found

We decided to go on with the problem domain and started using a W-diagram to expand upon it further and identify the parts needed to be researched to come up with a solution.

1.1 Initiating Problem

The initiating problem selected is *unknown terrain mapping and navigation.*

Chapter 2

Problem Analysis

Since the beginning of time, early human settlements were eager to explore their environment and surroundings. It did not take long, until the first humans started getting even further and become explorers. They started leaving marks and using landmarks to remember pathways and places. This primitive representation of prehistoric places and early history maps can be traced back to 24000-25000 BC [1]. Soon after, they started using maps, which revolutionized the way we navigate and the way we travel, - and therefore the field of Cartography was born. During the 19th century terra incognita (Latin, 'unknown land.') disappeared from maps, since both the coastlines and the inner parts of the continents had been fully explored. Today, using technology and satellites, Earth is completely mapped, yet still not completely explored. Around 95 percent of our oceans are still remains unexplored, considering that they take up 70 percent of the planet's surface [2]. This is mostly due to extreme conditions and high depths, that humans can not be put up against. As technology advanced and matured, remotely operated underwater vehicles (ROVs) become a popular way of exploring the depths of our oceans, due to their accessibility to places where humans could not possibly go before for a long period of time. In the meantime, interplanetary exploration took off during the mid-20th century with the start of the Cold War between the United States of America and the Soviet Union. This led to many great achievements in the field, like the first successful interplanetary encounter, where the US Mariner 2 flew by Venus [3] or when the Soviet Venera 3 made first impact on the surface of Venus [4]. The last successful program to date was the Mars rover CURIOSITY, which landed and still making progress in exploring and sending back scientific data of the planet Mars. Exploring planets for future-settlements and first-contact is very important in order to quench out human curiosity but also for advancing the different fields in science and technology.

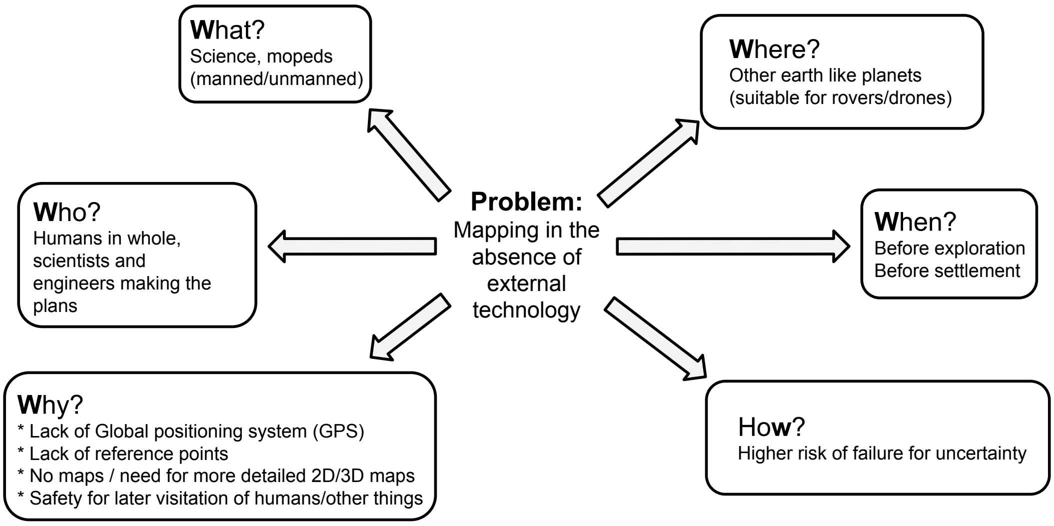

Figure 2.1: W-diagram

2.0.1 When is this actually a problem?

Mapping unknown terrains becomes a problem when new planets are discovered and mapping of the surface and its atmosphere is required for further exploration and investigation. Scientists use the so-called Earth Similarity Index (ESI) for mapping extrasolar planets (also called exoplanets) for potentially habitable places in the Universe. [5] [6]. The ESI implies many factors, like surface temperature and other Earth-like properties.

Another scenario is underwater exploration, where trained divers are unable to explore and map the underwater terrain due to its depth and dangerous circumstances. In these cases robots and submarines, that can either autonomously or remote-controlled can take up the task of mapping the bottom of the ocean. It is also much faster and more reliable than sending down people to do the same task.

Besides exploration, the task of mapping unknown terrains is used in hostage situation and natural disasters as well, where people cannot enter a specific area without that being mapped upfront for various factors, like radiation leakage or armed terrorists. One example would be the Fukushima Nuclear Plant catastrophe in Fukushima, Japan on March, 2011. After the leakage in the reactor, rescue forces and scientist used autonomous drones to map the inside of the factory [7], which was put under quarantine for high levels or radiation and therefore no person was allowed inside of the building without proper precautions. Drones and autonomous robots are perfect for scenarios like this.

2.0.2 Where does this problem actually occur?

Unknown terrain can be defined as a terrain where no mapping has been done before.

The bottom of the ocean is mostly sand, mud, and water []. This makes it difficult to navigate with a rover, but relatively simple to navigate with a submarine. In water, sensors that use sound need to be calibrated to work with the correct pressure of the water surrounding it, which varies with the depth of the water. If the water is murky, light based sensors may also not work, depending on the wavelength of the light they use. Light also refracts in water depending on the water density. It is possible to remote-control vehicles in the bottom of the ocean.

Other planets can be much more complicated to navigate. The consistency of they atmosphere and terrain may be not completely understood. This means that there is a higher chance of a rover being stuck on loose terrain, falling down sheer faces, and so on. It may also be the case that the planet has no atmosphere, so a drone would not be able to hover. One of the biggest issues with extraplanetary exploration is input lag. Other planets are very far away, which means that signals traveling to these distant places can take several minutes at least and years at most to reach from the Earth, thus automation is better suited for this task. Other planets share the issues that the bottom of the ocean has with sensors.

Disaster scenarios can also be said to be unknown terrain. Disaster scenarios means that the terrain might be loose or difficult to navigate, so a drone might be best suited for it. In most cases disaster scenarios happen in locations where the vehicle can be controlled manually.

2.0.3 How is it a problem?

To answer the question how does this problem occur, we have to look into some possible scenarios discussed above. Exploration of unknown terrain and environments has been practised for many years. It originates from the human curiosity and the spirit to explore and gather information about our surroundings, discussed previously.

When dealing with unknown environments, unknown does not strictly refer to the environment itself but the persons state of knowledge about the physics and composition of the given environment. In a known environment, outcomes from every action can more or less be calculated or estimated. Where as in an unknown environment, it is a matter of investigation and figuring out what works and what does not. In the unknown environment it is important to gain knowledge of how everything work, so that in the future it possible for an individual make the best possible choice and decisions in the environment. [8] Even though most of the land has been explored and is being used for its vast amount of resources, the time will come where planetary and ocean exploration becomes a key factor for our technological advancements and our resources. Ocean exploration is important because it provides data from deep-sea areas, which in turn will reduce the amount of unknown environments left on our planet. Gathering data and intelligence from the ocean also helps with managing the resources that are available in the deep-sea areas, so that future generations can benefit from them. The ocean also provides information about future environmental conditions and can help predict earthquakes and tsunamis. Investigating the deep-sea also reveals new ecosystems and possible sources for medication, food and energy, which are all vital for scientific advancements. [9]

Humans have always had never-ending interest and need to push science and technology to its limits, and then desire to achieve something even further than what is possible. The many challenges humans have faced has led to many benefits for our society almost since its creation. Space exploration helps further our understanding about the history of our universe and solar system. [10]

2.0.4 To whom and what is this a problem?

Unknown terrains and environments pose a big issue for scientists and engineers who want to explore these areas. Designing vehicles and devices for the deep-sea ocean or planetary exploration is impossible, without any background information on what environmental factors they will be dealing with or encountering. Exploration is essential when in the future new resources are needed for scientific and technological advancements, that currently our of reach.

In the long run humans in general will be affected by the lack of exploration. Alternative resources and habitable areas for expansion will be necessary in the future, when earth's natural resource deposits become depleted and there are less habitable places.

Scientists are heavily hindered by society, because it is becoming too focused on risks. Only 5 percent of the ocean has been explored, this leaves a large amount of areas untouched and mapped. Being concerned about taking risks is what will put the future development and science in jeopardy. [11]

2.0.5 Why is this a problem?

The reason why we need to explore other unknown terrains is to help us better understand everything around us and to be able to go to other planets. If the trips are planned well and we make a good 3D map of the terrain we can come up with better plans on the next mission or if we want to use this location at all.

The problems with navigating a robot in an unknown terrain is the lack of reference points that are needed to make a 3D map and also reference point for the robot itself to being able to navigate. That makes two challenges for us. One is for the robot to being able to navigate through a completely unknown terrain and at the same time make sense of it and come up with reference point that will be use to make a 3D map.

If a robot is successful with that task and we get back a detailed 3D map then the next mission can rely on that information and have a easier way to navigate.

On Earth, we have the GPS (global positioning system) that is a space-based satellite navigation system flying over the Earth [12]. Putting up a system like that on another planet cost a lot of resources and the cost to start with would not be beneficial in the beginning. GPS also does not penetrate water [13].

GPS theory

"The Global Positioning System (GPS) is a space-based satellite navigation system that provides location and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites. The system provides critical capabilities to military, civil, and commercial users around the world. The United States government created the system, maintains it, and makes it freely accessible to anyone with a GPS receiver."

The GPS satellites carry each an atomic clock and position the user when he is connected to 4 or more satellite. The satellites measure the time it take for the signal to go back and forth between the satellites and a GPS receiver.[http://www.loc.gov/rr/scitech/mysteries/global.html] There is also in development and space "GPS" system that would use the X-ray signal from dying stars to give up you location in space with about error of 5 km.

Both of those systems would not benefit our project in space since we would need a high accuracy location of each picture to make a 3D map model. Maybe later in the future when people will be moving to Mars another GPS system will be put up there. But for now we would need to use encoders and short to medium range high accuracy signals. But the signal systems would need to be different for what planet we would go to.

Photogrammetry theory

"Photogrammetry is the practice of determining the geometric properties of objects from photographic images. This is done by comparing and matching pixels or reference points across a series of photos.[http://um3d.dc.umich.edu/documents/123D-Catch-Field-Guide-1.pdf]"

In the simplest example, the distance between two points that lie on a plane parallel to the photographic image plane can be determined by measuring their distance on the image, if the scale (s) of the image is known. This is done by multiplying the measured distance by $1/s$.

Algorithms for photogrammetry typically attempt to minimize the sum of the squares of errors over the coordinates and relative displacements of the reference points. This minimization is known as bundle adjustment and is often performed using the Levenberg–Marquardt algorithm.

Photogrammetry could also be used in our project with AUV or a rover. The is no need for outside reference points to make the 3D model. But this setup is much more complicated to setup and maintain without an outside assistance. It would also need more pictures and higher resolution so more space on hard drives are needed. The algorithm needed to make the 3D model from the picture will need a lot of power and memory. So on board rendering would be really hard.

For higher resolution maps and more detailed the use of photogrammy is beneficial.

But to start with it would be easier to take another approach.

Reference points theory

To make a 2D or a 3D map a reference point is needed. It can be GPS point of every picture taken. It can be comparing two pictures together and overlapping them. You can also combine both options. But with the lack of GPS in space and the cost of memory and power to make an overlapping 3D map, we need some other way. For an example Mars has a thin atmosphere on it. So using sound sensors is possible. The sensors would need to be calibrated for a difference in speed of sound on Mars. Other sensors like light (x-ray, laser and others) can also be used. That would mean setting up and array of sensors so the rover or AUV could connect to them and know it's position. The use of encoders and the wheels of the rover is also a anther solution but you would need to be sure to have error calculation in it. Because sometimes tires will move in a circle but there is no traction.

2.1 Autonomous Vehicles and Robots

Autonomous robots or vehicles can work for an extended period of time gathering information from its surroundings to be able to work without human intervention. The robot or vehicles gathers different kinds of data, depending on what the goal of the robot it.Positional data can be utilized for navigation and path finding in a known and unknown environment. Intelligent autonomous devices are able to adapt to changes happening in its surroundings. Currently there are many robots on the market that are self-reliant, ranging from autonomous vacuum cleaner to drones and helicopters. [14]

Simple autonomous robots use ultrasonic sensors or infrared to manipulate itself if it detects obstacles. The is useful for obstacle avoidance and mapping of unknown areas, where the robot through a reference point can pin-point the obstacles it has encountered along the way. More advanced robots use vision to grant them the ability to see their surroundings, algorithms analyse the camera data and gives the robot depth perception, which grants the robot the ability to instantly identify objects and locate them immediately. [15]

There exists two kinds of autonomous robots, a single computer autonomous robot and insect robots. The single computer autonomous robot uses its own on-board computing unit to do its computations and decisions, whereas the the insect robots are a fleet a many robots who are controlled by a single separate computing unit. The advantage of having a single computer autonomous robot is that the tasks it performs can be done using more computer resources. It has the possibility of utilizing the computing power to its full potential, instead of relying on a separate unit that is also making decisions and calculations for many other robots. The individual robot in the insect family is simple, but the whole robot fleet can be advanced and possibly perform sophisticated tasks, that a require multiple simpler robots. [16]

2.2 Path finding and mapping

Pathfinding is done by a computer, where it uses plotting to find the shortest path between two different points. It can be viewed as a more efficient way of navigating a maze. There exists pathfinding algorithms that are used for software simulations, but also for mobile robot navigation.

A common pathfinding algorithm is A* (A star) and its extended version D*.

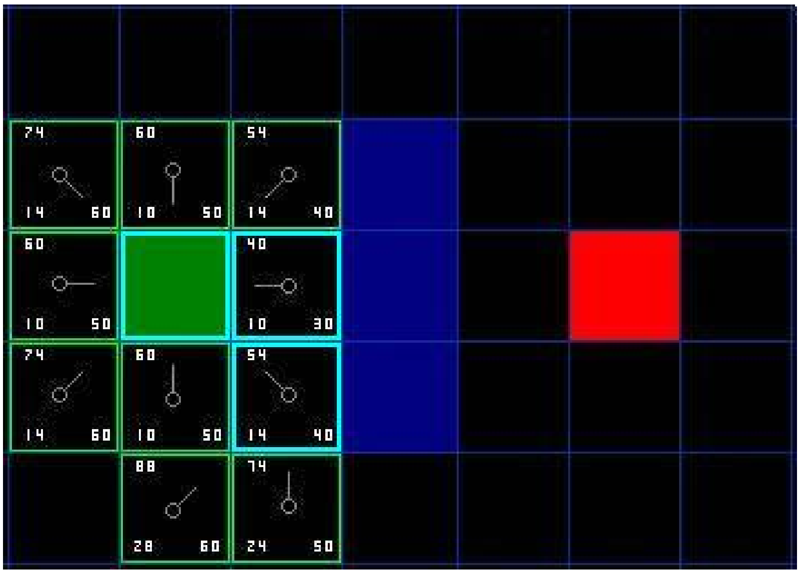

Figure 2.2: Upper-left number is F, Lower-left G and Lower-right H

The A* algorithm is most commonly used in video games. The algorithm determines that cost of movement from the start to the given generated destination(G), in relation to the estimated cost of movement to its final destination(H). Based on the current destination the possible surrounding paths are analysed and the path with the F value(F = G + H)becomes the chosen path. [?]

Simple autonomous robots navigate by the use of infrared LEDs or by the use of photo-resistors and LEDS, by following lines drawn on a surface.
Some autonomous robots and vehicles use multiples of different range sensors and other sensory equipment, to map and locate themselves in indoor and outdoor environments. The map that is generated can be used to keep track of static items in the environment such as structures and difference in terrain, but the map also distinguishes non-static items such as humans and other moving objects. Since the maps are created by the vehicle itself whilst exploring, this technology can be used with or without GPS [?] [?]. Robots and vehicles have been created using this technology to explore known and unknown environments. Because of advanced algorithms and hardware these autonomous devices are capable of performing tasks more efficiently than humans, but also in places that are unsafe and hard to reach.

Autonomous robots also use these tools to work together. Using a shared map, the robots can keep track of one another and either perform tasks together or separately, depending on what is required from them.

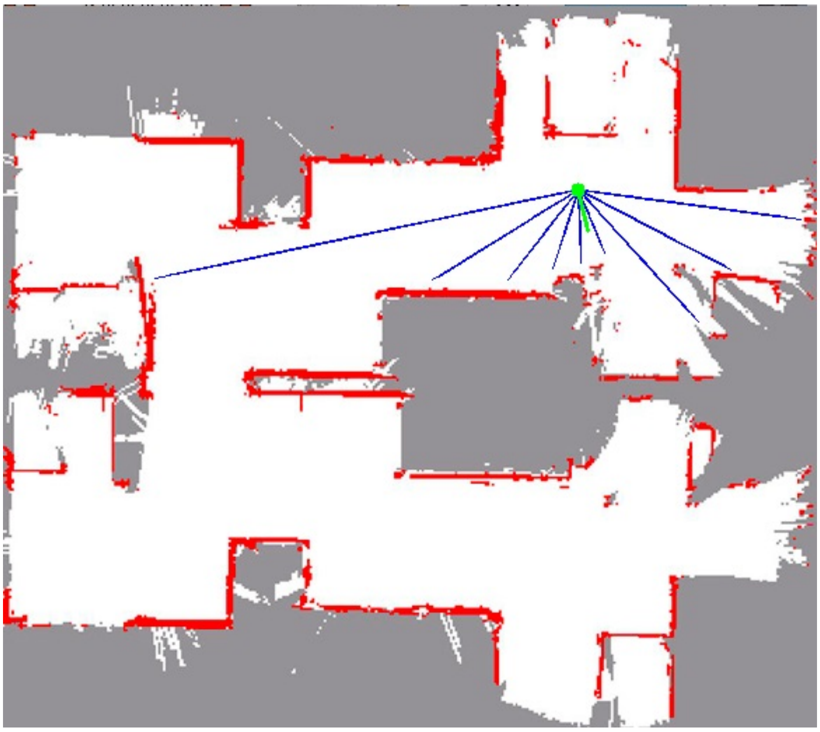

Figure 2.3: Laser range map

Laser range finders and sonar arrays are used to navigate and determine the shortest possible path to a given destination. The sensory equipment is used to give the autonomous robot a sense of distance towards objects in an environment, giving it vital data regarding optimal travel directions [**?**].

Chapter 3

Problem Definition

3.1 Hypothesis

Hypothesis

3.2 Problem Definition

Problem Definition

Chapter 4

Development

4.1 Description

Description and following chapters

Chapter 5

Discussion

Discussion

Chapter 6

Conclusion

Conclusion

Chapter 7

Perspective

perspective

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Chapter 8

Appendix

appendix