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Lunar Landing Site Selection and Hazard Detection and Avoidance

Abstract

This literature review describes the Lunar Mission 1 project, and explores the Shackleton Crater region of interest as the proposed landing site, in terms of its illumination and communication conditions, in addition to its geological potential. This report also contains an explanation and analysis of a cutting edge Hazard Detection and Avoidance system, using Artificial Neural Networks, which would be utilised during the landing on the lunar South Pole. Publication search engines including Google Scholar, Research Gate and Web of Knowledge provided the research and images used.

Introduction

Lunar mission 1 is an international space science and exploration mission aiming to explore deep into the surface of the south pole of the moon, before leaving a historic record of human life that could survive for up to a billion years. The area being explored is on the edge of the Shackleton Crater, and will use wire-line technology to drill from 20-100m. Overall, this mission is predicted to cost approximately $1.5 billion, and is due to take place in 2024. The lunar geology could ultimately reveal the history of the solar system, and this mission acts as a stepping-stone towards further space exploration.

Part of selecting the most appropriate landing zone is considering any landing hazards or complications due to the location, and determining how much accuracy is necessary. This includes the surface conditions, and would indicate whether the area is appropriate for a future manned science base.

Shackleton was formed over 3 billion years ago, is 21 kilometres is diameter and is located on the lunar South Pole. The reason Shackleton is so attractive for the prospect of lunar exploration is that after NASA's Lunar Reconnaissance Orbiter (LRO) spacecraft mapped the crater's structure and natural reflectance, it returned data to suggest that up to 22% of the surface within the crater could be made of ice.

The spacecraft found that the walls of the crater, that are occasionally illuminated, are brighter than the floor – despite it being colder and therefore having less evaporation occurring. One theory is that seismic moonquakes caused by meteorite impacts may have led to the outer layers of soil on the walls eroding, revealing the brighter material. Another theory is that water from water-bearing debris, such as asteroids, has been kept in so-called polar cold traps for billions of years, since they constantly impact the moon.

Methodology

The process of sourcing and utilising academic journals began with recommendations of search engines, including Google Scholar, Research Gate and Web of Knowledge. The first subject I searched was Shackleton Crater, in order to build my introduction and gain knowledge on why this was the region of interest, and the scientific potential it may have. Soon after having found a few useful journals, I became restricted, as I didn't have membership to any of the websites that otherwise require large payments in order to access the full texts. Fellow Lunar Mission 1 students experienced the same problem, and upon presenting this issue to our supervisor, we were soon assigned Bath University logins that were recognised by the websites, thus giving us full access to the journals. Additionally, when continuing our research at home, we were given instructions to install a VPN, allowing us to again access these journals away from the University. This made the process much easier.

After researching Shackleton, I moved towards the Hazard Detection aspect of the landing. I was fortunate to find a research paper only published a few months ago, with cutting-edge technology not yet used in HDA systems. Overall, I would consider the information sourcing technique to be relatively straightforward, especially since the subject of space exploration and lunar missions is vast, with many previous and alternate missions offering similar information – thus additionally increasing information reliability.

Results

Illumination

Shackleton crater was first continuously photographed in 1994 by Clementine – the Deep Space Program Science Experiment, which was a joint space project to make scientific observations of the moon. The project was successful, and highlighted which areas on the lunar surface were in permanent darkness during the winter, and which areas were illuminated for over 50% of the lunar day. As previously mentioned, the darker regions are more likely locations of ice deposits, while the more illuminated areas would be more appropriate for a lunar base, since it would be able to run on solar power, without the need for other power sources. There isn't any area on the surface with permanent illumination.

The inclination between the lunar orbit and ecliptic is around 5°, but the Moon's equatorial plane only has a 1.5° inclination to the ecliptic. This means that the sun will always seem close to the horizon on the poles, so areas will be likely permanently illuminated or darkened.

There are two main regions of interest on the Shackleton rim; SR1 and SR2. These two areas are within 10km proximity of each other, and collectively receive solar illumination for 98% of the lunar day. SR1 is the main point of interest, with a 273-day period of illumination, while SR2's longest illumination period lasts 234 days. Another area further north from the lunar South Pole that would also be attractive as a landing site was Malapert Peak.

Communication

When discussing visibility between Earth and the Moon, a line of sight between the landing site and centre of the Earth is used, since the location of ground control is yet to be decided. Since the moon always shows the same side on Earth, positioning a spacecraft on the equator of this side would ensure it is always seen. However, at the poles, the visibility of Earth is only roughly 14 days per monthly cycle. When the independent patterns of Sun and Earth visibility are combined, it shows that if the landing occurs just as the illumination window begins, the site will also have direct visibility from Earth, but only for 3 days. If the drilling experiments and results cannot be completed within that timeframe, there would be delay of around 20 days until the next opportunity. For each specific landing site, there is one favourable landing window annually – so in the case of launch delays, the spacecraft will have to remain in low lunar orbit.

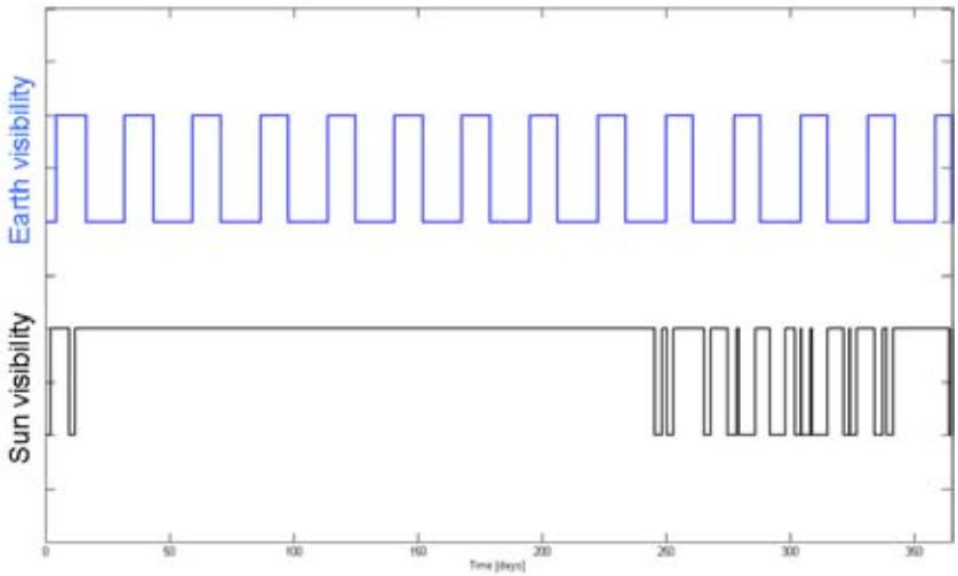

Figure 1: Time Frame of Annual Earth and Sun Visibility from Shackleton[1]

Hazard Detection on lunar surface

The entry descent and landing phase plays a key role in ensuring success of the Lunar mission; any problems encountered during landing often result in loss of the spacecraft. This means that hazard detection is paramount to ensure a safe landing – and that the computation is complex enough to retarget or change the landing site without human intervention, since this is an unmanned mission. Hazard detection and avoidance (HDA) systems have developed since the Apollo missions; beginning with studies estimating surface major irregularities using a scanning ranging laser. NASA has, since 2006, improved these systems, with studies involving using active ranging sensors in order to create a Digital Elevation Map. One of these examples is LIDAR, which is a technology used to measure the distance between observatories and reflectors on the moon, in order to measure the position of the moon.

For a landing site to be classified as safe, there are four requirements: surface roughness, size of the area, slopes, and visibility from sensors. In terms of surface roughness and local obstacles to the landing site, the probability of a successful landing also depends on the dimensions of the landing gear of the probe.

Nominal Hazard Detection and Avoidance Manoeuvre

Recent research has shown that HDA systems can be based upon Artificial Neural Networks (ANN)[2]. An ANN is a machine learning method, a system that develops from data, which generally consists of its architecture – the variables involved and their relationships, the activity rule, which will define how the activities of the neurons change in response to one another, and the learning rule which occurs over a longer time scale. In this system it is assumed that the input is just images from a monocular camera, and telemetry of altitude and attitude, however by involving more input, for example LIDARs, the system will be even more accurate.

It is also assumed that the HDA manoeuvres will first be carried out at an altitude between 2500 and 100m - where the landing site is within the sensor's field of vision. At this point, the lander should be at a near vertical attitude. This is known as the HDA High Gate, and the vertical downward and horizontal velocities should be around 15-30ms^{-1} and 5-15ms^{-1}. Next the system will scan the site and build a hazard map, before computing the landing trajectory and commanding a diversion manoeuvre to a more accurate landing zone. The manoeuvre will position the lander vertical to the landing target, at an altitude around 250-500m. The velocities will decrease to around 5-10ms^{-1} and 2-4ms^{-1}. Another hazard avoidance manoeuvre will occur next, with the lander scanning the area and creating a hazard map on a smaller scale. If necessary, the landing site, trajectory or diversion manoeuvre will be updated. The final point of manoeuvre is known as the Terminal Gate. It is located around 30-50m above the target landing site. At the Terminal Gate the lander should have a vertical attitude, with no horizontal velocity, and a vertical speed of less than 3ms^{-1} – and from here, the lander will follow a vertical trajectory towards the ground at constant speed. See Figure 2 for an overview.

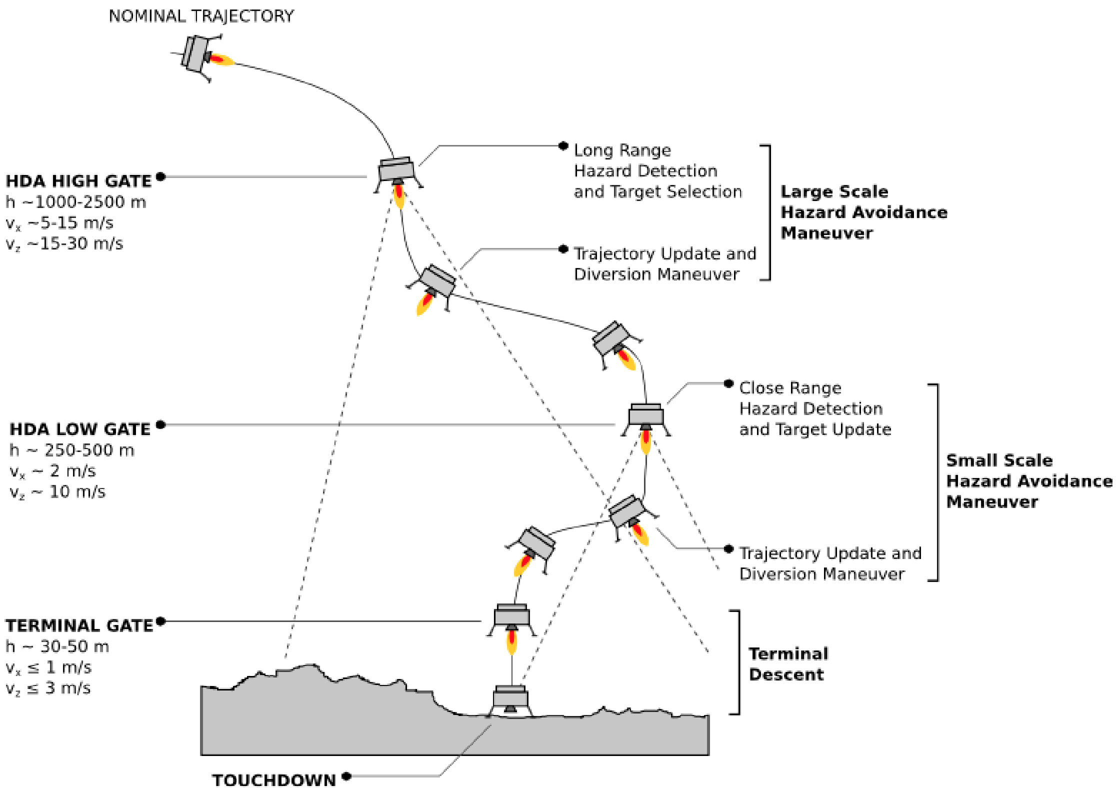

Figure 2: Diagram to summarise process of HDA manoeuvre[2]

When it comes to the system architecture and how the ANN works within it, there are four predominant steps: the first is preprocessing, where the raw images are gathered and corrected (perspective-wise); the second is the analysis stage by segmenting these images at different scales and extracting low levels of information; the third is the processing stage of the index information into a hazard map; and the fourth is the target landing site search, where the hazard map is used to provide the best landing site. The hazard detection and avoidance system is assumed to operate in near vertical attitude, so it corresponds with the approach manoeuvres. Therefore if there are deviations in attitude when the raw images are gathered, they will be corrected by applying a perspective transformation, before building the hazard map.

There are two types of artificial neural network architecture under consideration with this system – a feedforward multilayer neural network and a cascade neural network. The feedforward multilayer has a simpler design, is more commonly used in pattern recognition, and consists of an input layer, many hidden layers, and the output; with the input being processed by each layer sequentially. The more complex the architecture scheme becomes, the slower the optimization process, which is all too crucial in this circumstance. Overall, a single hidden layer of 15 neurons proves most effective. Cascade networks have layers made up of only one neuron, and input of each is the original input, plus the output of the previous hidden layers. At the beginning of the training, there is only the input and output layers, with hidden neuron layers added to increase optimization.

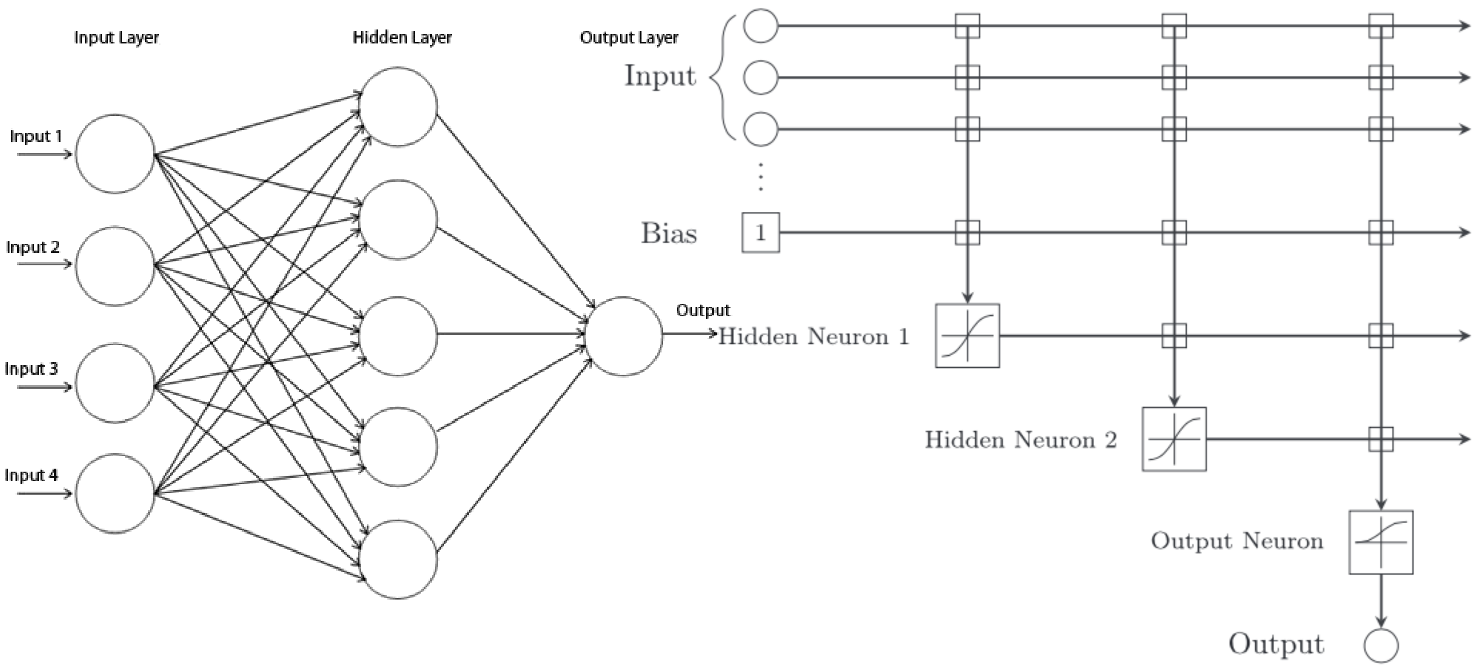

Figure 3: On the left is the feed forward network, with a predetermined structure, and one of more neurons per hidden layer[3]. On the right is the cascade structure, with each hidden neuron added progressively.[2]

Discussion and Evaluation

I believe SR1 is the most viable landing site option – by using 3D maps found during my research, one can analyse the topography of the regions of interest. Shackleton Rim 1 is located on the intersection of two slopes, resulting in the area on the peak having a circular target zone. This increases the necessary landing accuracy, especially if the lander were to be positioned downhill, where the ridge could mask illumination. Malapert Peak, however, has a plateaued terrain with larger surface area, allowing the target-landing zone to take the shape of a strip. This reduces the required landing accuracy, but the region itself receives far less illumination (203 days compared to SR1s 273) and has less geological interest.

By using a hazard detection and avoidance system similar to the one described in my results, the computation should be complex enough to land accurately within the SR1 region. The only limitation regarding the concept of Artificial Neural Networks is that, due to it being such an innovative and recent idea, I struggled to find other research. However there should be much more available by the time this mission is sooner approaching.

In terms of the potential of a future manned base in the same region, the idea of using tower-mounted solar arrays seems feasible. Analyses of research have shown that in particular regions of interest on the lunar South Pole where the Sun is very low or even below the horizon, there is far greater potential for illumination at higher altitudes than terrain level. This also shows promise for longer night survivability, as well as the possibility of constant illumination. Therefore, by successfully investigating this concept further for future missions, the mission duration and extent of the landing site would also be increased.

During my last day at Bath University, I, amongst the other students, had to present my findings. After I presented, I was asked questions and given suggestions by the students who had researched similar aspects of the mission. This proved useful to my research, and one particular question that was raised was whether we could use satellites already utilised for missions including the Mars Curiosity landing to help with our communications. I think this would be a good concept to investigate, in case the illumination window finishes before the experiments have been carried out. Additionally, another student's presentation contained calculations into the approximate time it would take for the borehole to be drilled. He concluded that it would take around a month, since the drill is very small and the hole is very deep. This time is longer than I had assumed, and would therefore affect the communications, since it would take longer than the 14 days of continuous Earth visibility. Since there is a large continuous illumination period from the sun, using satellite communication during the lack of Earth visibility would solve the issue. Moreover, students highlighted the 3 second time delay between lunar and mission control communications, and whether it could cause problems in terms of the landing – however, with a hazard detection system as complex as the one described, it wouldn't be controlled from Earth once in lunar polar orbit, and if something did go wrong, it would be out of our control regardless of the time delay.

Other contributions from students that impact my investigation included research into the lunar dust, which apparently reduces the surface visibility from an altitude as high as 30m. This would largely affect the Terminal Gate manoeuvre of hazard detection, and would mean more care would need be taken into ensuring a safe landing. Therefore, instead of following a vertical trajectory at constant speed until touchdown, the lander should decelerate and prepare for touchdown at an earlier altitude.

Acknowledgements

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References

1. Vanoutryve, Benjamin et al. "AN ANALYSIS OF ILLUMINATION AND COMMUNICATION CONDITIONS NEAR LUNAR SOUTH POLE BASED ON KAGUYA DATA". N.p., 2016. Web. 23 Aug. 2016.

2. Lunghi, Paolo, Marco Ciarambino, and Michèle Lavagna. "A Multilayer Perceptron Hazard Detector For Vision-Based Autonomous Planetary Landing". *Advances in Space Research* 58.1 (2016): 131-144. Web.

3. Sergiu, Ciumac. "Financial Predictor Via Neural Network". *Codeproject.com*. N.p., 2011. Web. 11 Sept. 2016.

4 .Spudis, Paul D. et al. "Geology Of Shackleton Crater And The South Pole Of The Moon". *Geophys. Res. Lett.* 35.14 (2008): n. pag. Web.

5. Bussey, D. Ben J. et al. "Illumination Conditions At The Lunar South Pole". *Geophysical Research Letters*. N.p., 1999. Web. 23 Aug. 2016.

6. Stergiou et. al., Christos. "Neural Networks". *Doc.ic.ac.uk*. Web. 8 Sept. 2016.