Shamrock: Hazard Detection for Asteroid Landing

Lidar Technologies

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Introduction

Lidar is a technology used for accurately measuring distances. There are a wide range of lidar sensor types and applications, many of which are applied to the field of navigation and satellite to gain a high level understanding of a surface or system. Lidar is used in space exploration, geology, civil engineering, and environmental engineering to render models of oceans, forests, rocks, caves, cities and space surfaces.

Technology/Background

Lidar works as follows - a lidar sensor sends out a pulse of laser light, and the light is reflected back from a surface and received by the lidar sensor. This time taken for the pulse of light to be returned to the sensor is used to calculate the distance from the sensor to an object. Thus, when an object is detected, there is a pulse in the returned signal where an object was hit. One important thing to note is that the pulse of light travels at a known speed, the speed of light, thus the calculation to find the distance is fairly straightforward.

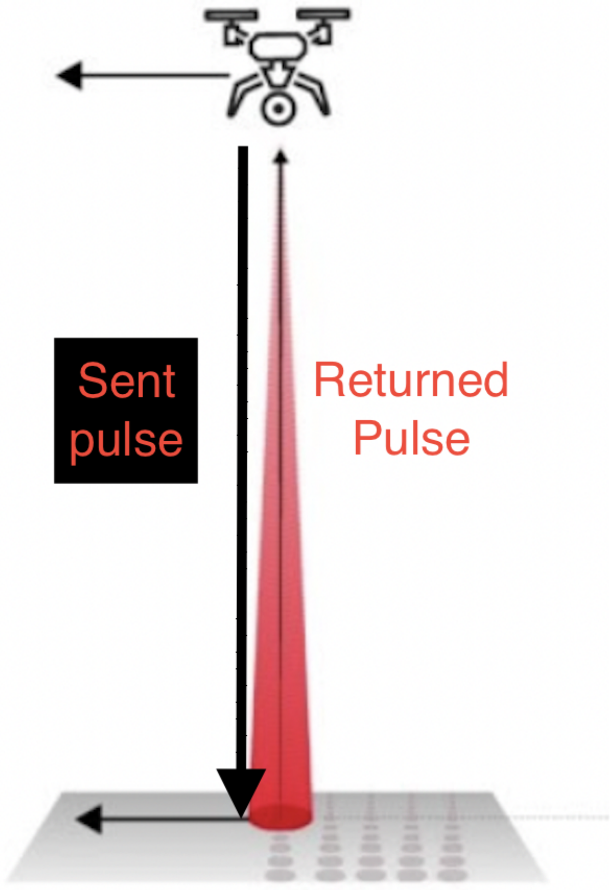

Figure 1: Light pulse and returned light pulse. The time for the pulse of light to be received is used to find the distance.

When using Lidar sensors, it is important to acknowledge their strengths and weaknesses. There is a distinct advantage to using Lidar - measurements tend to be precise and create a better special map of an area being studied. However, most lidar sensors are expensive and require heavy computation loading, as Lidar datasets tend to be quite large.

Flavors of Lidar

One advantage of using Lidar is the tunability of the sensor - the number of light pulses sent out per second can be increased or decreased based on the application.

The light that lidar sensors emit is based on the application of the lidar sensor. For more geological/land-based applications, the Lidar's pulse usually has a wavelength of around 1.5 nm, which is not harmful to the human eye. However, when using lidar to detect features in oceans (a technology called bathymetric lidar), green wavelength light is used to map ocean floors, which passes more easily through oceanic waters.

In addition, there are a few types of Lidar sensor types that use this basic technology pulse and return pulse idea. To the right (Figure 2) is an image that shows two types: one is a scanning lidar sensor, which sends out light in a line of lidar pulses, mapping out a space in points by moving the sensor around. On the right of Figure 2 is flash lidar, which takes lidar data in large quantities, like the way brightness from a scene is returned in a camera. The scanning Lidar is more traditional, but flash lidar has many advantages as taking scanning lidar can be tedious and requires time to physically move the sensor around. Each type of Lidar has its unique applications and advantages.

Since Lidar maps distances in a space, it is often coupled with other sensors to gain even more information about a space. Sensors that give information about location are useful - think GPS or acceleration readers (IMU).

When coupled with sensors like a GPS, Lidar can be used in what is called a navigation system, where the Lidar distance measurements help make decisions about where to go/ what to do. Examples of this are when an autonomous car detects a person using Lidar in a street, it stops moving or avoids that person.

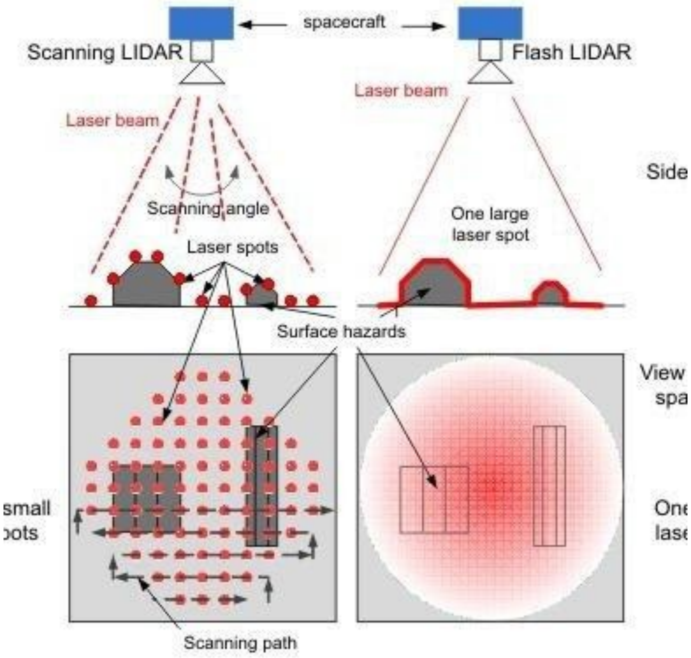

Figure 2: Scanning (left) vs. Flash (right) Lidar

Scattering

Due to the nature of Lidar, there are some challenges that arise when using Lidar sensor data. One challenge is the effect of *atmospheric scattering (*G. Roy*)*. Because Lidar heavily relies on the pulse that is sent out to be returned, any obstacle from this light being returned negatively impacts readings. The main idea of atmospheric scattering is that if enough particles are in the path of the lidar pulse, then light will be reflected off of those objects, delaying the pulse's return and distorting the returned signal (Mamouri).

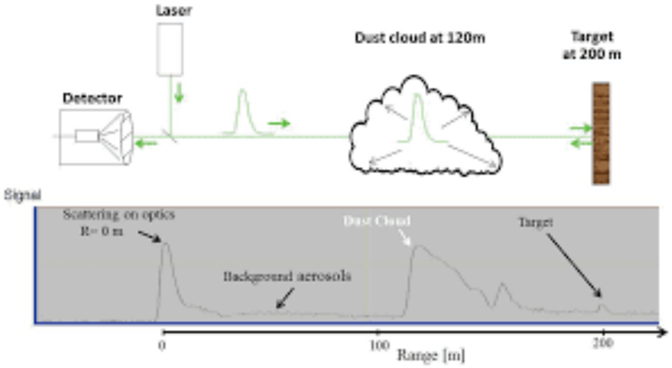

Figure 3: Example of a pulse that will scatter due to the dust cloud.

Applications to Asteroids

Lidar sensors are often used in navigation systems for their ability to accurately map a space or surface. In terms of applications in space, Lidar is often used to map the surface of planets and asteroids (Xueming). There are many failures of detecting hazards from just photographs of a surface. For example, dark scenes, like those often found in space, lead to amplified noise in a returned photo. Shadows also cause areas of a scene or surface where information is lost. Lidar technologies don't have any 'dark' areas, such as shadows, and are accurate regardless of the lighting condition. Lidar also helps capture information about the atmosphere and dust conditions in a system.

The sampling rate, or data taken per given time, is often calculated based on the application. For closer range Lidar data, samples are taken and pulsed more often than when a high-level map of an area is being taken.

Applications to Shamrock's Senior Design Project

Our team will use Lidar data from a sensor attached to a drone. The Lidar method to be used in scanning Lidar, and thus we will fly the drone in a methodical zig-zag line to capture the Lidar data for the "asteroid" surface. Due to the absence of dust in our simulated asteroid surface, there will likely be no dust cloud or cloud Lidar information gathered. However, we will use the returned pulse signal and timing to find the height of the drone relative to the asteroid set. By changing the sampling frequency that these pulses are sent and received, a 3-d dataset for the surface will be made with varying resolution.

This portion of the Lidar project will be the most complex – creating a 3-d map using Lidar data and other sensors. Because the location of each measurement is not known, this data must be found using IMU and TRN (terrain relative navigation) methods.

Photographs taken from the will be mapped to a photo of the whole set, allowing for a semi-accurate reading of where the drone was when each lidar data point was taken. Our team will also be measuring acceleration and filtering this data to find another estimated location for the drone at a given point.

After the location has been established through these methods, the time stamped Lidar distance measurement will be used to pinpoint where the actual height of the drone was at a given time.

One assumption we are making in these measurements is that the drone is staying relatively steady in terms of its height when the data is being taken. We hope to achieve this by flying the drone slowly and visually ensuring the drone does not drift down or up during data acquisition runs.

The final step to using our Lidar data was to find the most sloped and tallest areas from a given run. The Lidar algorithm interpolates the data to fill in the areas where Lidar data wasn't taken. Sharply increasing or decreasing slopes will be used to determine where a hazardous landing area is. After determining where the most safe and unsafe areas for landing are, the algorithm will create a hazard map, which takes Lidar data and creates a physical map of safe and unsafe areas. Two other parts of our project will be creating hazard maps based on drone photographs. Our project will combine the three hazard maps to create a final hazard map to illustrate where would be safest area to land on.

Results

Below are three images showing the Lidar interpolation and hazard mapping process using one test run of data.

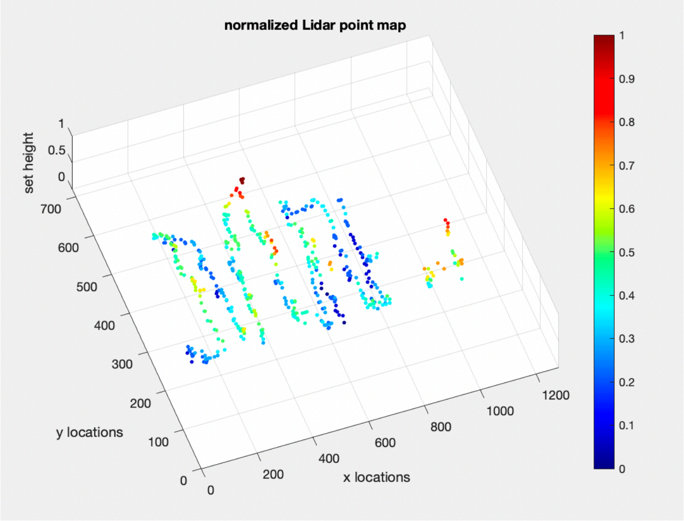

Figure 4: Raw data points from the lidar data. Higher heights are denoted using red, lower heights are denoted using blue.

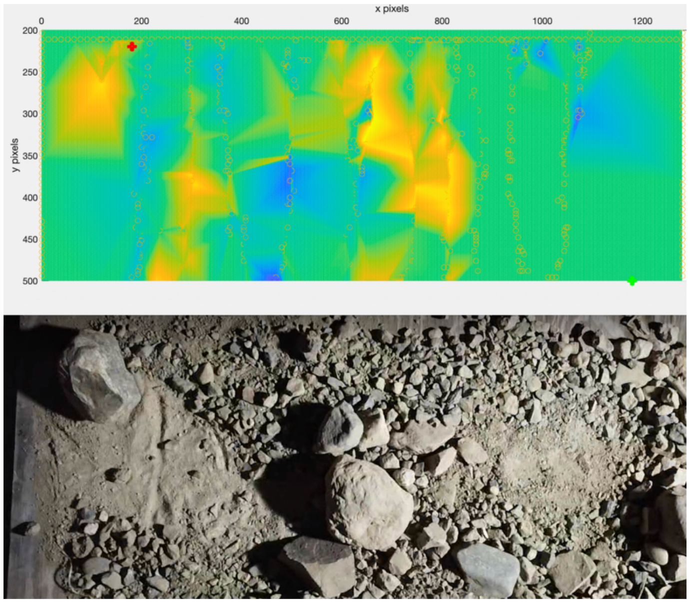

Figure 5: A heat map showing interpolated Lidar data from a run – note the zig zag pattern of the data collection. Yellow areas denote a hazardous area, while bluer areas denote safer landing sites.

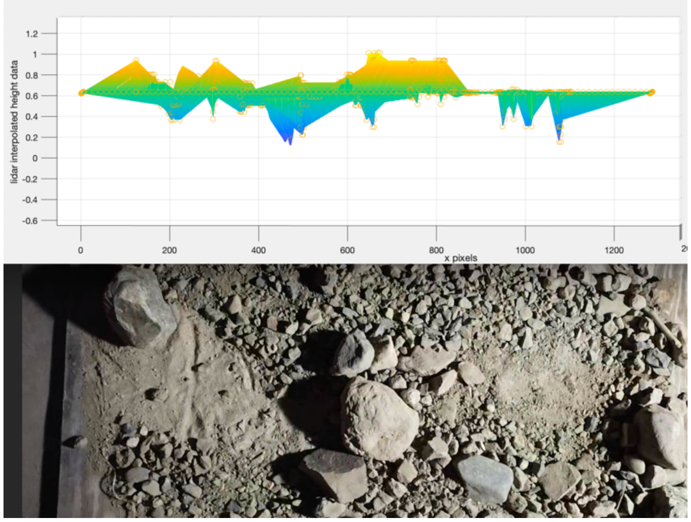

Figure 6: A cross section of the interpolated Lidar map to see the rises and falls of the asteroid set.

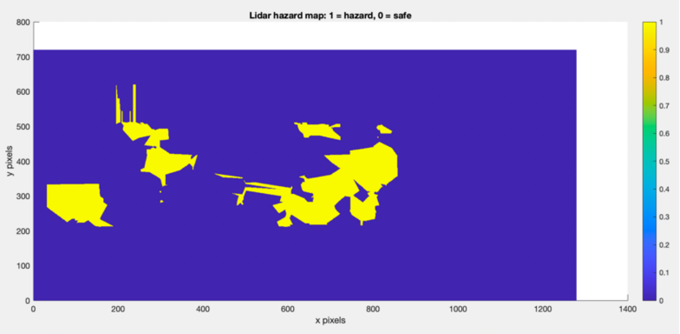

Figure 7: The final hazard map produced from one run of Lidar data after taking any value above a threshold to be a hazard.

Conclusion

Lidar is a powerful technology which can capture and map a 3-d space or surface. Where photography often falls short in mapping spatial surfaces, lidar excels. In space navigation, Lidar provides a way to gather information about the atmosphere (like dust clouds). In addition, different types of Lidar technologies provide a range of capabilities and applications.

References:

Farzin Amzajerdian, Diego Pierrottet, Larry Petway, Glenn Hines, Vincent Roback, "Lidar systems for precision navigation and safe landing on planetary bodies," Proc. SPIE 8192, International Symposium on Photoelectronic Detection and Imaging 2011: Laser Sensing and Imaging; and Biological and Medical Applications of Photonics Sensing and Imaging, 819202 (19 August 2011); https://doi.org/10.1117/12.904062

G. Roy, S. Roy, X. Cao (2014), Helicopter Flight Test of the Obscurant Penetrating Auto Synchronous Lidar (OPAL) in Degraded Visual Environments: Part II – See-through Capability Assessment

Mamouri, R. E, & Ansmann, A. (2014). Fine and coarse dust separation with polarization lidar. Atmospheric Measurement Techniques, 7(11), 3717–3735. https://doi.org/10.5194/amt-7-3717-2014

McManamon, Paul. (2019). LiDAR Technologies and Systems - 11.1.5 Eye Safety. (pp. 102-112,450-464). SPIE. Retrieved from https://app.knovel.com/hotlink/pdf/id:kt012EEQV7/lidar-technologies-systems/eye-safety

Whiteway, J., M. Daly, A. Carswell, T. Duck, C. Dickinson, L. Komguem, and C. Cook (2008),
Lidar on the Phoenix mission to Mars, J. Geophys. Res., 113, E00A08, doi:10.1029/2007JE003002

Xueming Xiao, Meibao Yao, Hutao Cui, Yuegang Fu, Safe Mars landing strategy: Towards lidar-based high altitude hazard detection, Advances in Space Research, Volume 63, Issue 8, 2019, Pages 2535-2550, ISSN 0273-1177, https://doi.org/10.1016/j.asr.2019.01.005.

Zhang, J., Singh, S. Low-drift and real-time lidar odometry and mapping. Auton Robot 41, 401–416 (2017). https://doi-org.ezproxy.library.tufts.edu/10.1007/s10514-016-9548-2

Image Credits:
Figure 1:
https://www.youtube.com/watch?v=94wU1yWFIfY

Figure 2:
https://www.researchgate.net/figure/LiDAR-vs-Flash-LiDAR-technologies-Courtesy-wwwfosternavnet_fig3_261333968

Figure 3:
https://cradpdf.drdc-rddc.gc.ca/PDFS/unc195/p801936_A1b.pdf

Figure 4:
https://en.wikipedia.org/wiki/Bicubic_interpolation