Remote Sensing Teams LiDAR Landslide Mapping Project Continues Despite COVID Related Setbacks

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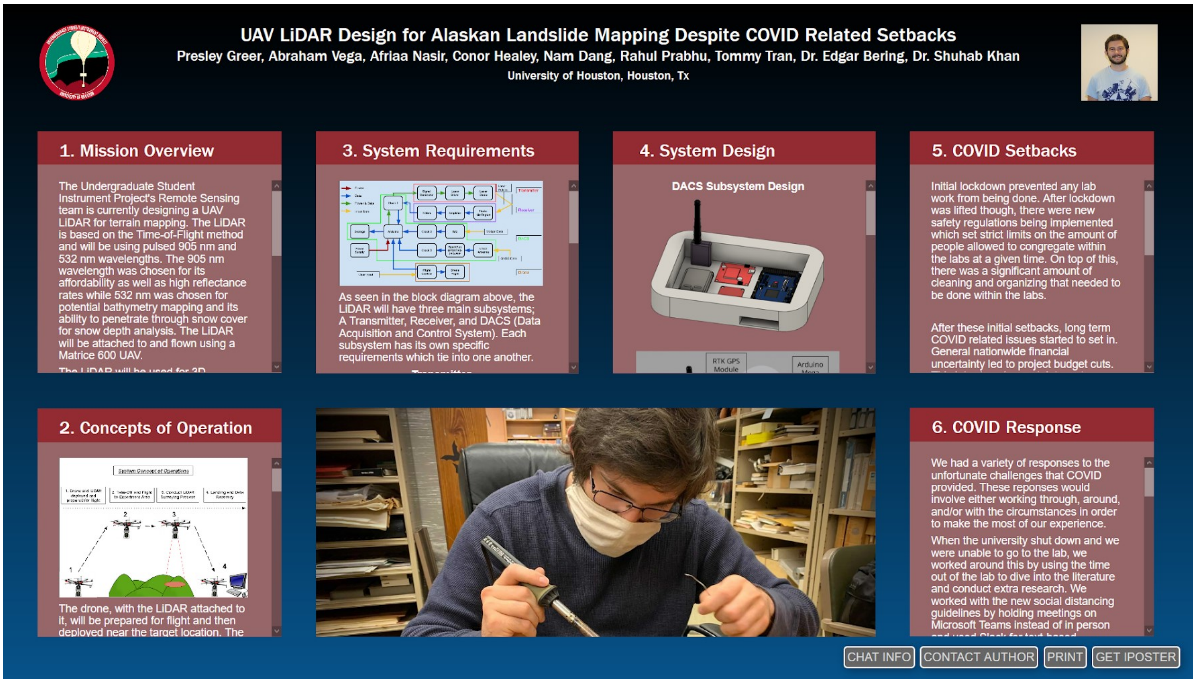
Abstract

The University of Houston's USIP (Undergraduate Student Instrument Project) Remote Sensing team is designing and building an airborne LiDAR with the intention of using it to 3D map landslides and for possible mineral exploration. The maps will be used to conduct landslide analyses and failure predictions while the magnetometer feedback will be used to determine the presence of possible metallic minerals in the area. The LiDAR will employ the use of two lasers with different output wavelengths; 1550nm will be used for typical terrain mapping and 532nm will be used for snow depth reading to extrapolate the underlying terrain characteristics. Trade studies are currently underway for the lasers, sensors, IMU's and magnetometers. It is planned for the LiDAR to collect data near Fairbanks, Alaska, with further research into potential study sites being conducted. The scan pattern is still being decided on with the most likely option being a circular scan for the 532nm laser and a zig zag pattern for the 1550nm laser both set at a maximum scan angle of 20 degrees. The Remote Sensing team has been facing unforeseen obstacles due to the nature of the COVID-19 pandemic. Upon initial lockdown, weekly scheduled in person meetings and lab work were prohibited. After the first week, though, new mediums of communication were established. The USIP group decided to conduct online meetings through Microsoft Teams and use Slack for text-based communication outside of meetings. Unfortunately, lockdown and COVID chaos brought psychological issues to group members that can be difficult to overcome. This included high stress levels caused by the chaotic events as well as isolation-induced depression. After some deliberation amongst all USIP groups, it was decided to occasionally hold non work-related meetings through Microsoft Teams. This reduced some of the isolation depression by relaxing, talking, and eating pizza. After lockdown restrictions were lifted, the university had begun preventing the previous number of students from being in the lab at once. On top of that, individuals were understandably hesitant to go to the lab, often opting out. Despite this, small groups of USIP students have been going to the labs to clean, disinfect, and get the lab ready for work. New lab procedures have also been created to adhere to social distancing norms.

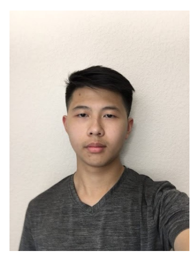
UAV LiDAR Design for Alaskan Landslide Mapping Despite COVID Related Setbacks

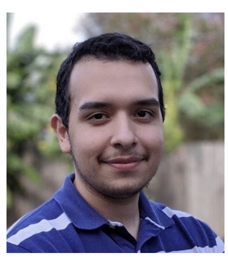


Presley Greer, Abraham Vega, Afriaa Nasir, Conor Healey, Nam Dang, Rahul Prabhu, Tommy Tran, Dr. Edgar Bering, Dr. Shuhab Khan

University of Houston, Houston, Tx

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1. MISSION OVERVIEW

The Undergraduate Student Instrument Project's Remote Sensing team is currently designing a UAV LiDAR for terrain mapping. The LiDAR is based on the Time-of-Flight method and will be using pulsed 905 nm and 532 nm wavelengths. The 905 nm wavelength was chosen for its affordability as well as high reflectance rates while 532 nm was chosen for potential bathymetry mapping and its ability to penetrate through snow cover for snow depth analysis. The LiDAR will be attached to and flown using a Matrice 600 UAV.

The LiDAR will be used for 3D landslide mapping along the Tanana River nearby Fairbanks, Alaska. The goal is to create 3D landslide maps and DEM's with a spatial resolution of 0.3 - 1 m. These maps will then be used to conduct landslide analysis and to study landslide dynamics.

Science Traceability Matrix

<table>
<tr><td colspan="2" rowspan="2">USIP
Undergraduate Student
Instrument Project
Remote Sensing Team</td><td colspan="4">Objective #1: Design and build a LiDAR instrument</td></tr>
<tr><td colspan="4">Objective #2: Use the LiDAR to make a 3D map of a landslide</td></tr>
<tr><td colspan="2">Mission Objective(s)</td><td colspan="4">To make a dual laser pulsed time of flight LiDAR light enough to be flown by a drone and capable of making terrain maps with up to a 1 meter resolution</td></tr>
<tr><td>Science Objectives</td><td>Measurement Objectives</td><td>Measurement Requirements</td><td>Instruments</td><td>Instrument Requirements</td><td>Data Products</td></tr>
<tr><td rowspan="6">What is the probability of landslide failure?</td><td rowspan="2">3D Landslide Terrain map</td><td>Distance from ground at given moment & position at that moment</td><td>LiDAR</td><td>_cm Altitude resolution, _ns time resolution, timing of measurements to match up data</td><td>Time stamped point cloud</td></tr>
<tr><td>Positional accuracy above landslide region</td><td>SparkFun GPSRTK2-ZED-F9P & OpenLog Artemis</td><td>Measure up to 0.01m coordinate precision when RTK enabled. Can receive L1/L2 bands</td><td>3D Coordinates, Time</td></tr>
<tr><td rowspan="3">Determine surface Composition/ geologic environment</td><td>Field Observations</td><td>Hammer & Shovel</td><td>Field work, on ground sample collection</td><td>Geologic Samples</td></tr>
<tr><td>Images</td><td>Camera</td><td>Centimeter photograph resolution</td><td>Photographs</td></tr>
<tr><td>Relative Reflectance</td><td>detector/receiver</td><td>Record amount of light reflected vs light used</td><td>Reflectance curves/graphs</td></tr>
<tr><td>Determine vegetation of area</td><td>Real & NRI's of Landslide</td><td>Camera</td><td>~1-10 cm photograph resolution</td><td>Photographs</td></tr>
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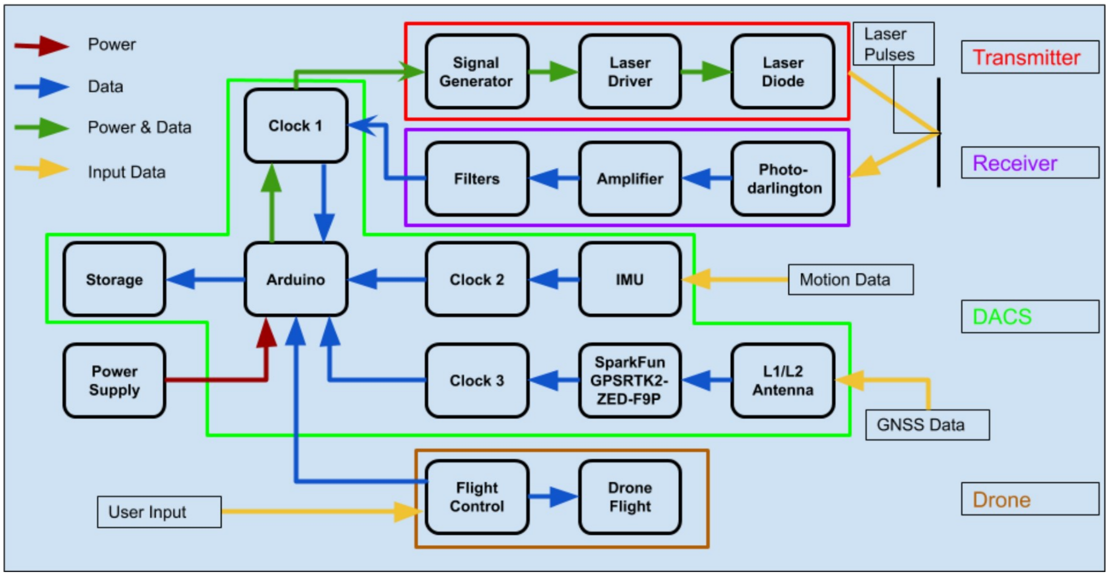
3. SYSTEM REQUIREMENTS



As seen in the block diagram above, the LiDAR will have three main subsystems; A Transmitter, Receiver, and DACS (Data Acquisition and Control System). Each subsystem has its own specific requirements which tie into one another.

Transmitter

The transmitter will emit 905 nm and 532 nm laser pulses. For an unambiguous range of 100 m, the max pulse frequency will be 1.5 MHz.

Receiver

The receiver must be capable of detecting both 905 nm and 532 nm wavelengths. It's optical receiving power requirements can be determined by the LiDAR equation: $P_r = \frac{P_t \rho \mu^2 A_r}{\pi R^2}$

P_r is the power received

P_t is the power transmitted

ρ is the reflectivity of the target

μ is the atmospheric transmission

A_r is the area of the receiver

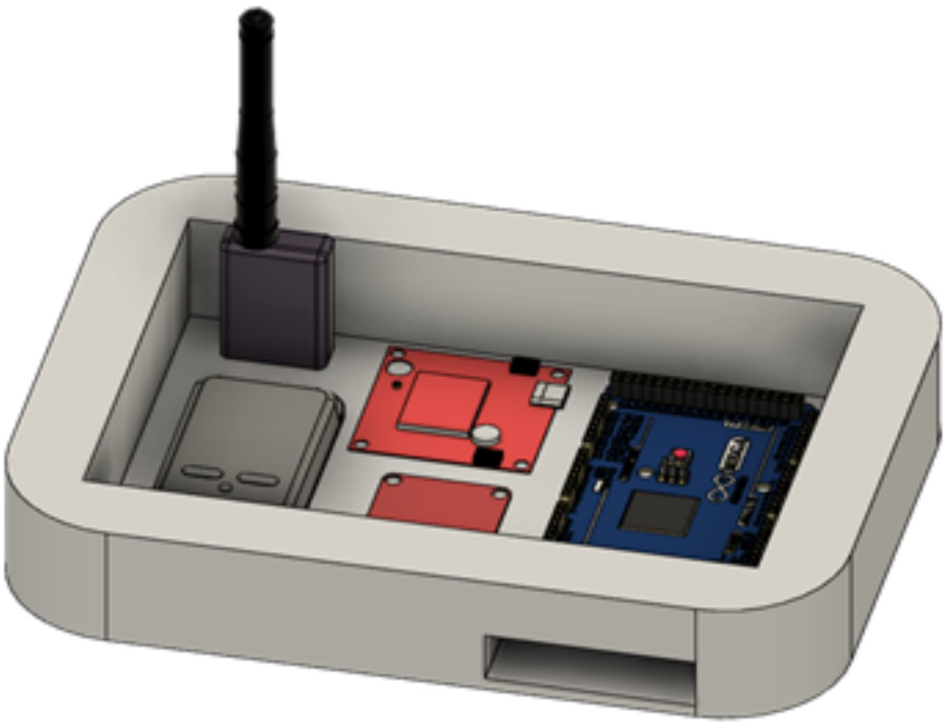
R is the range

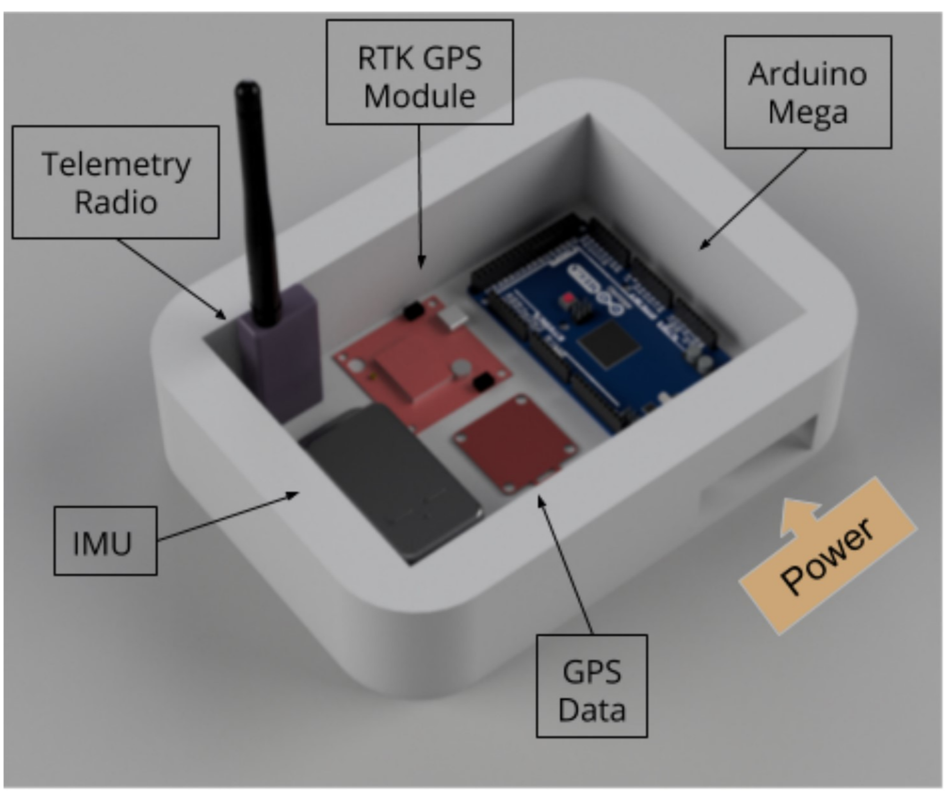
DACS

The Data Acquisition and Control System will keep track of the LiDARs position and orientation with less than 2 cm coordinate accuracy and within 1° orientation accuracy.

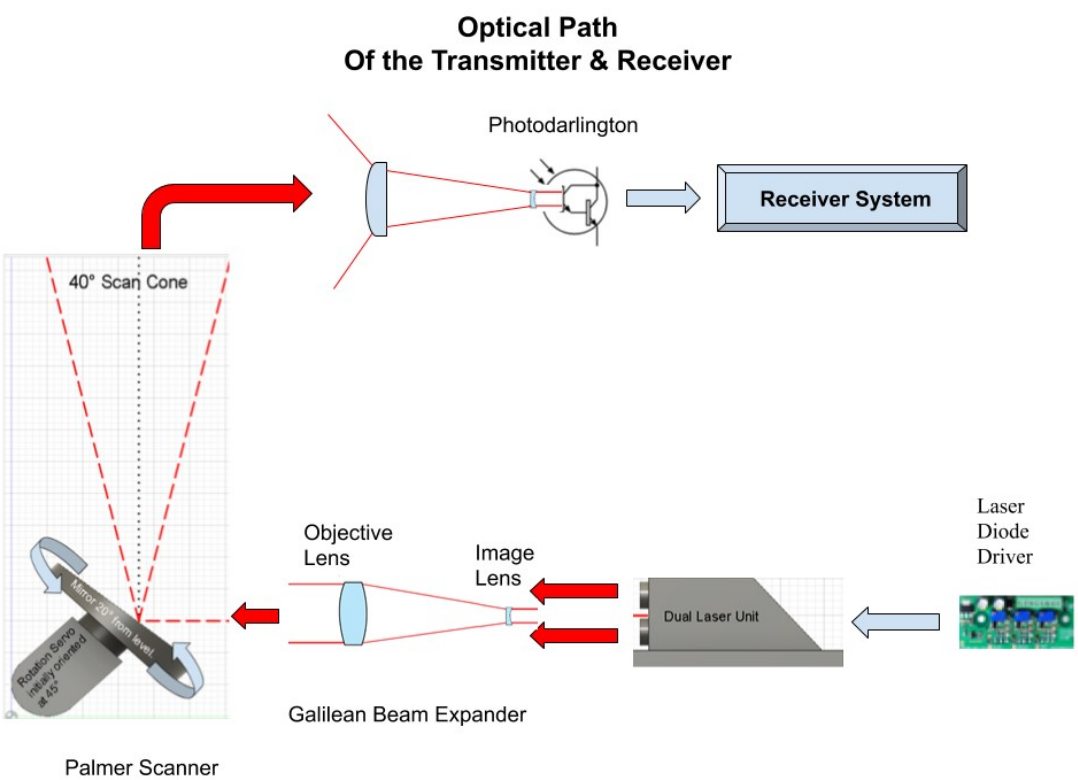
4. SYSTEM DESIGN

DACS Subsystem Design





Transmitter & Receiver Design



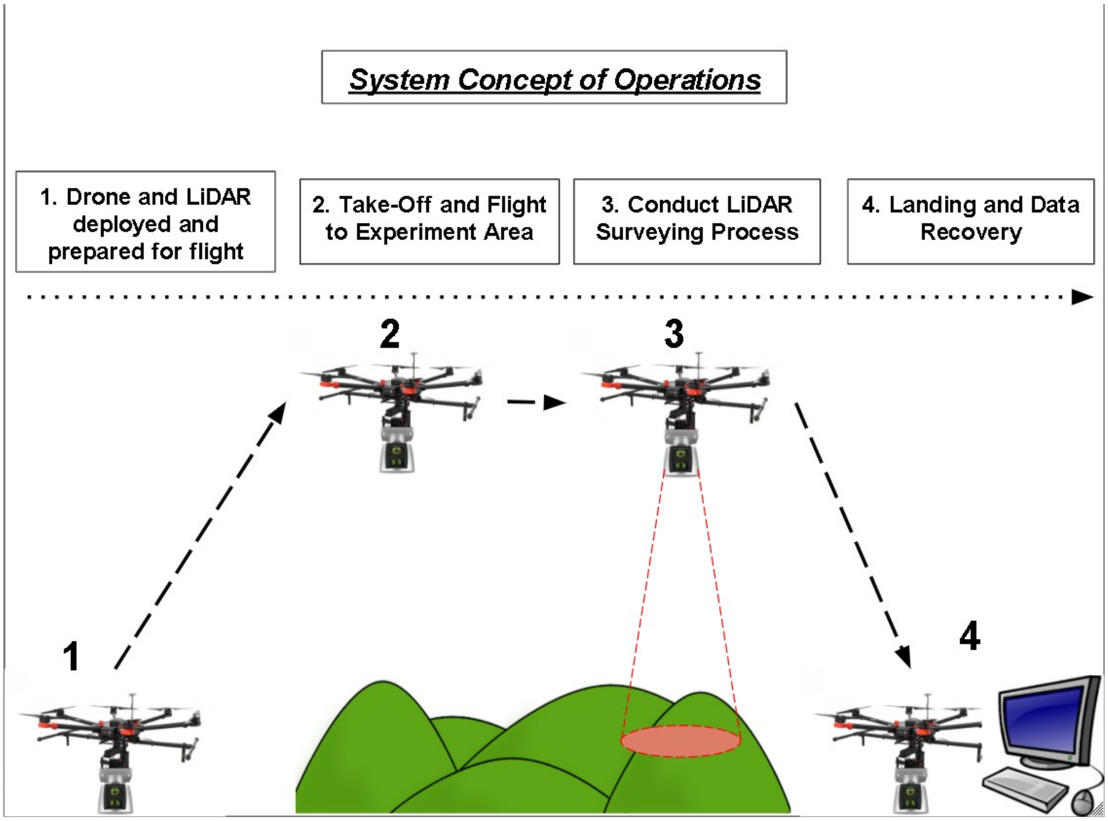
5. COVID SETBACKS

Initial lockdown prevented any lab work from being done. After lockdown was lifted though, there were new safety regulations being implemented which set strict limits on the amount of people allowed to congregate within the labs at a given time. On top of this, there was a significant amount of cleaning and organizing that needed to be done within the labs.

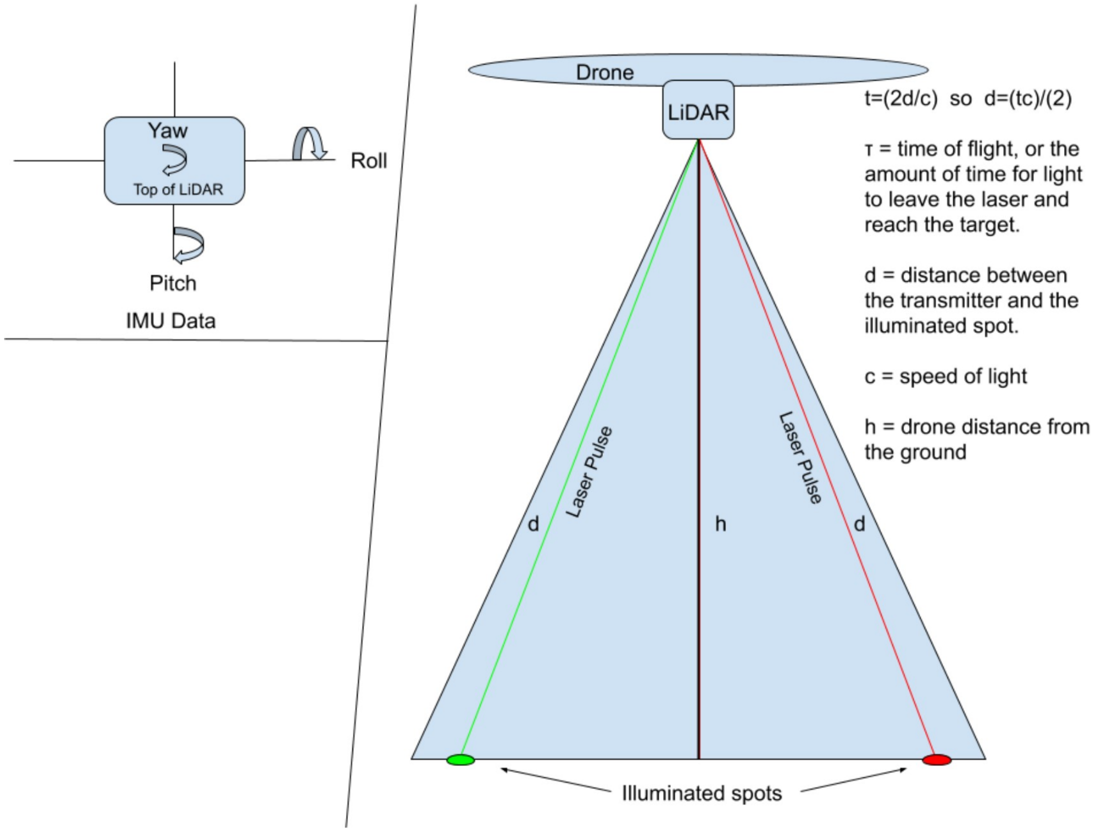
After these initial setbacks, long term COVID related issues started to set in. General nationwide financial uncertainty led to project budget cuts. This introduced uncertainty as to whether we would be capable of even buying the parts required. It's also uncertain if we will even be able to go to Alaska come Spring 2021 due to the potential of another outbreak and interstate travel quarantine requirements.

Living through a pandemic affected everyone's personal lives in various ways. It's safe to say that COVID has provided everyone with an astronomical amount of stress and anxiety. This mental and emotional baggage has caused an understandable loss in moral which has led to a decreased workflow. The social isolation following the cancelation of our in person weekly team meetings adds to that.

2. CONCEPTS OF OPERATION



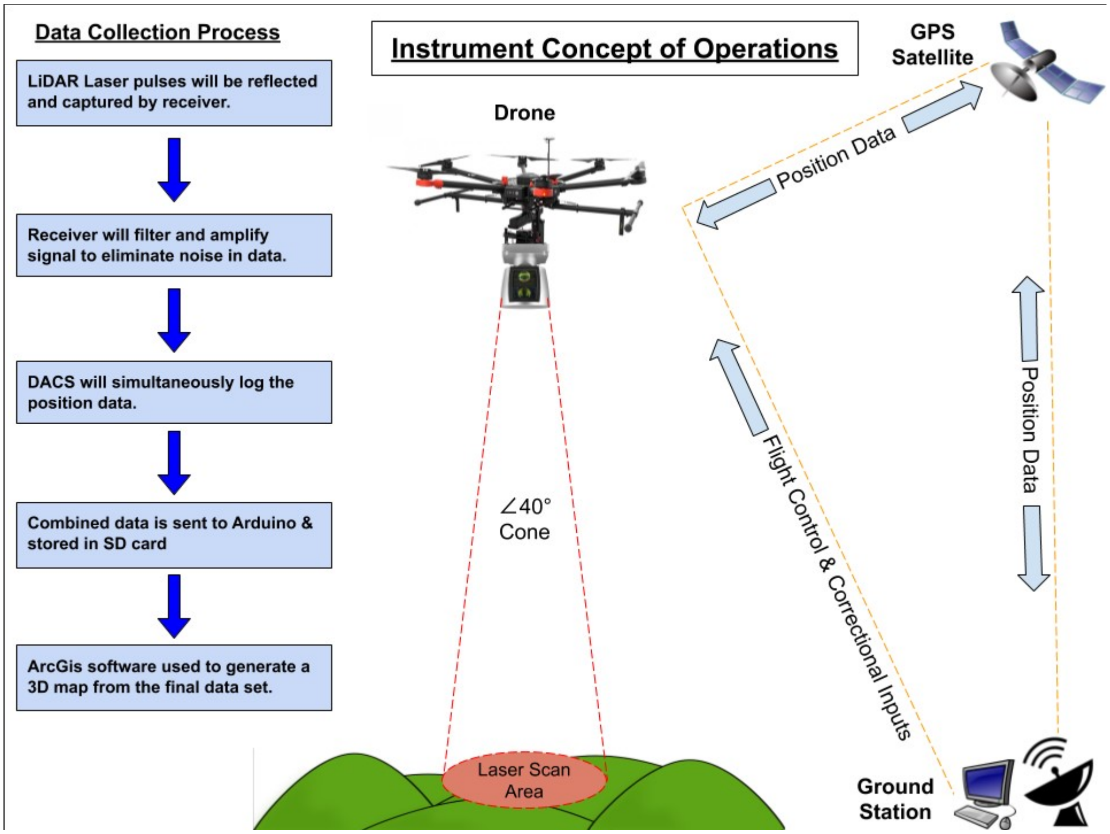
The drone, with the LiDAR attached to it, will be prepared for flight and then deployed near the target location. The drone will then fly the LiDAR over the survey area while the LiDAR fires laser pulses in a circular scan pattern. Once the survey is complete the drone will fly back to the base station and the data will be recovered from the LiDAR.



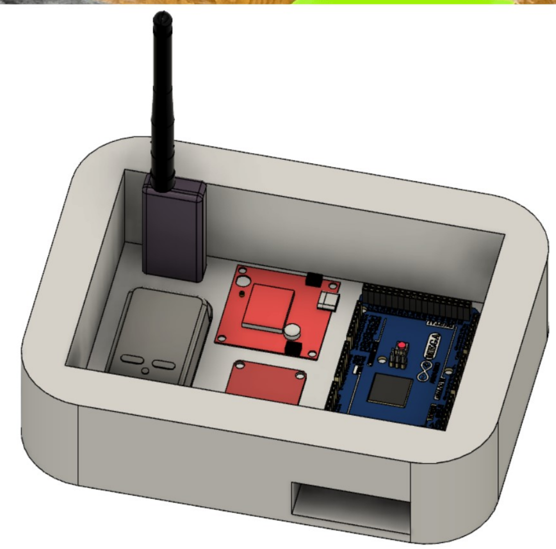
While the LiDAR is being flown over the target location it will be firing two pulsed lasers. The range equation $d = \frac{tc}{2}$ will be used to determine the distance between the transmitter and the illuminated part of the ground where:

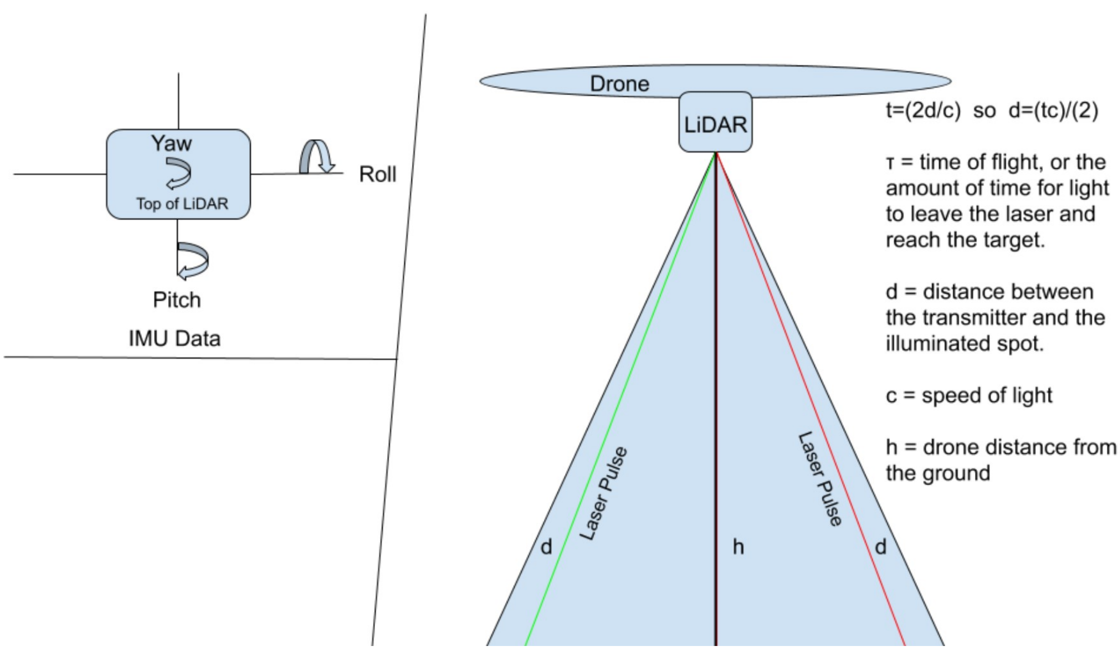
- d is the distance between the transmitter and the illuminated part of the ground
- t is the amount of time for the pulse to leave the transmitter and reflect back into the receiver
- c is the speed of light.

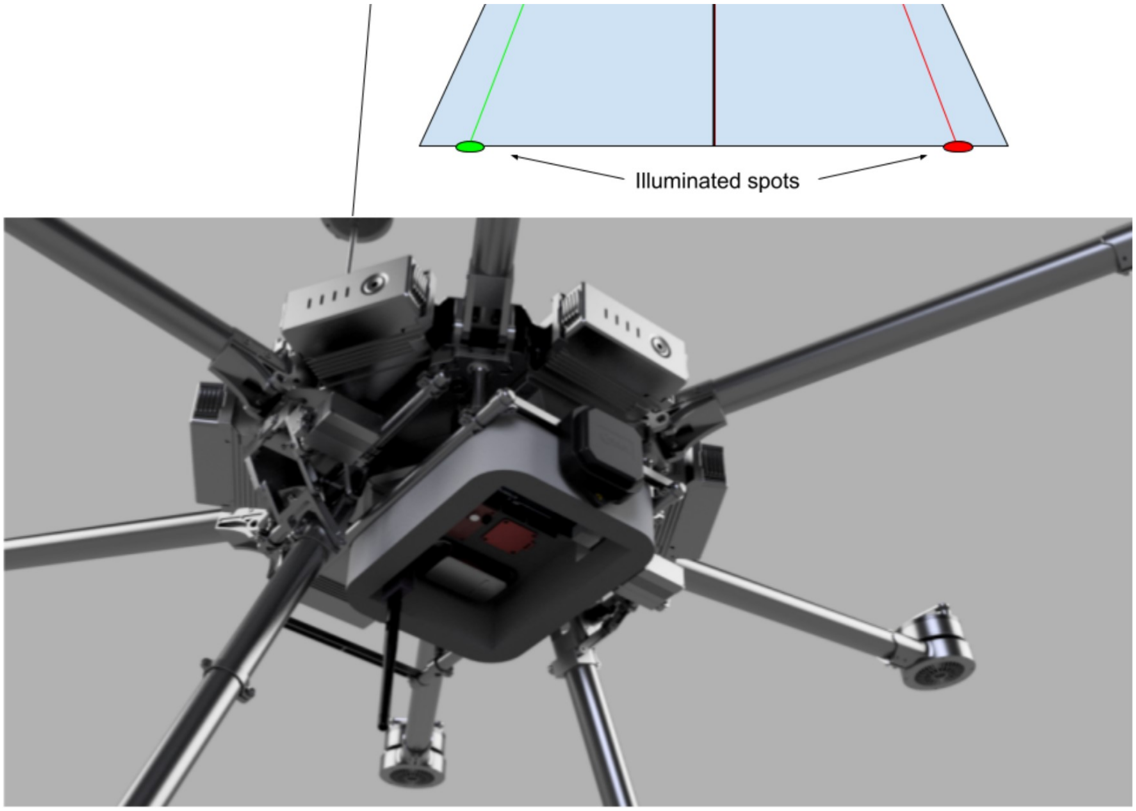
Meanwhile, the IMU (Inertial Measurement Unit) will be recording the LiDAR's pitch, yaw, and roll to correct for orientation.



While the LiDAR is recording the laser pulses and IMU data, the RTK GPS (real time kinematics global positioning system) on the lidar will be receiving positional data from satellites. A ground station with an RTK GPS will also be receiving and generating positional and correction data. The correction data will then be transmitted to the GPS device on the LiDAR. This will provide precise positional data to accompany the laser pulse and IMU data which will all be used to make a point cloud map of a landslide. From there the point cloud can be used to generate a 3D map and DEM (Digital elevation model).




Yaw
Top of LiDAR
Roll
Pitch
IMU Data
Drone
LiDAR
t=(2d/c) so d=(tc)/(2)
τ = time of flight, or the amount of time for light to leave the laser and reach the target.
d = distance between the transmitter and the illuminated spot.
c = speed of light
h = drone distance from the ground
Laser Pulse
Laser Pulse
d
h
d


Illuminated spots

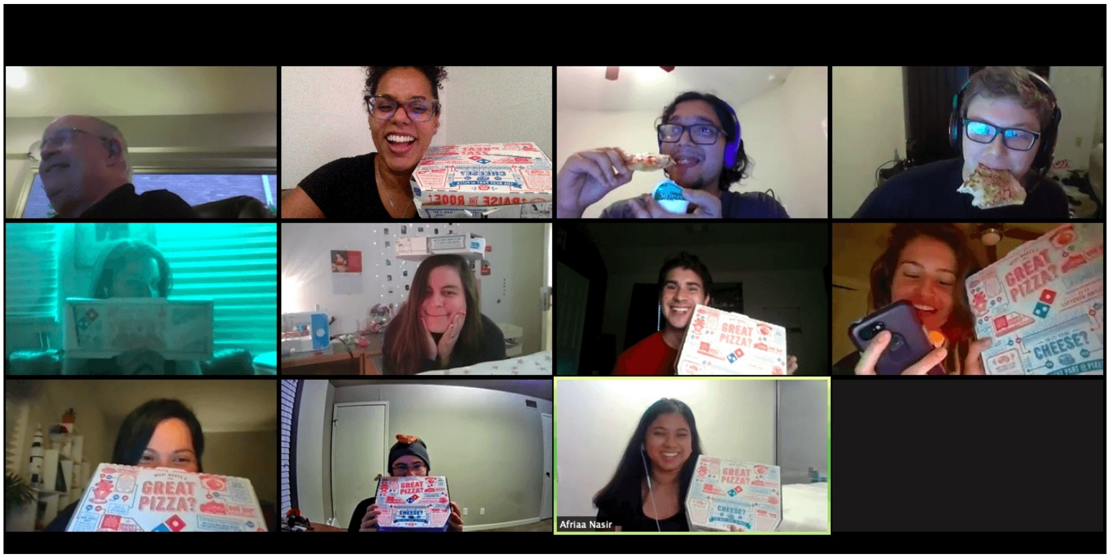
6. COVID RESPONSE

We had a variety of responses to the unfortunate challenges that COVID provided. These reponses would involve either working through, around, and/or with the circumstances in order to make the most of our experience.

When the university shut down and we were unable to go to the lab, we worked around this by using the time out of the lab to dive into the literature and conduct extra research. We worked with the new social distancing guidelines by holding meetings on Microsoft Teams instead of in person and used Slack for text-based communication outside of meetings. When it came down to going to the lab, a lab schedule was made with a limitted amount of people being allowed in the lab at a given time.

Dr. Bering worked through the reduced funding by securing financial support through his network. This has allowed us to begin purchasing parts without worrying that there might be enough funding to complete the project. We still might be unable to go to Alaska come March 2021, but we've decided to work around that by finding potential landslide locations within Texas that can be mapped. We're currently looking into areas along the Balcones Fault.

As far as team moral, an online pizza party was held with all pizza's free of charge. This helped raise everyones spirits. Pictures of the pizzza party can be seen below.

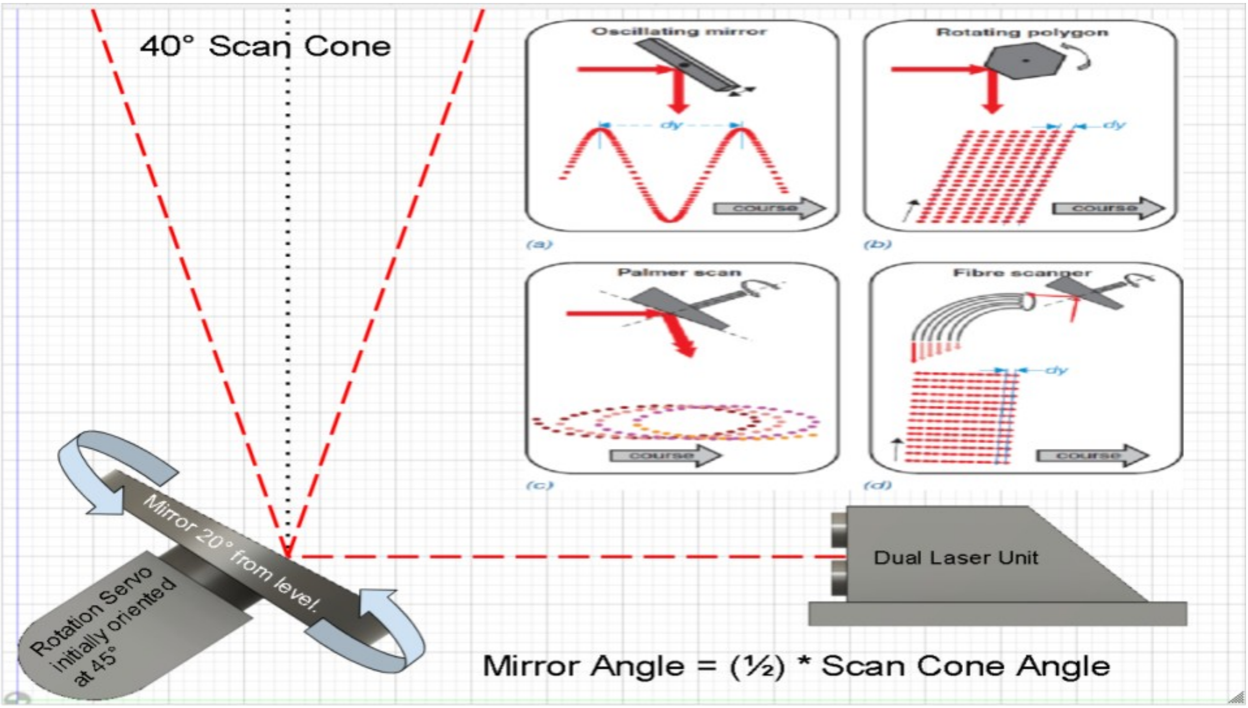

GREAT PIZZA?
CHEESE?
Afriaa Nasir

Remote Sensing

Supplemental Material/Information

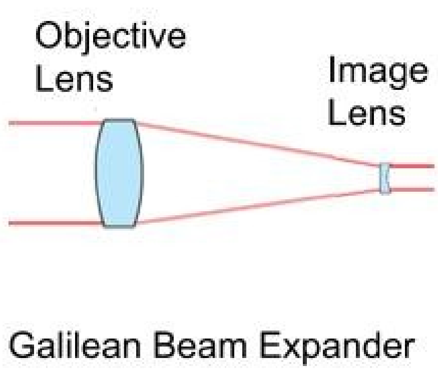
Presley Greer, Afriaa Nasir, Abraham Vega, Tommy Tran, Conor Healey, Rahul Prabhu

Laser Scan Pattern

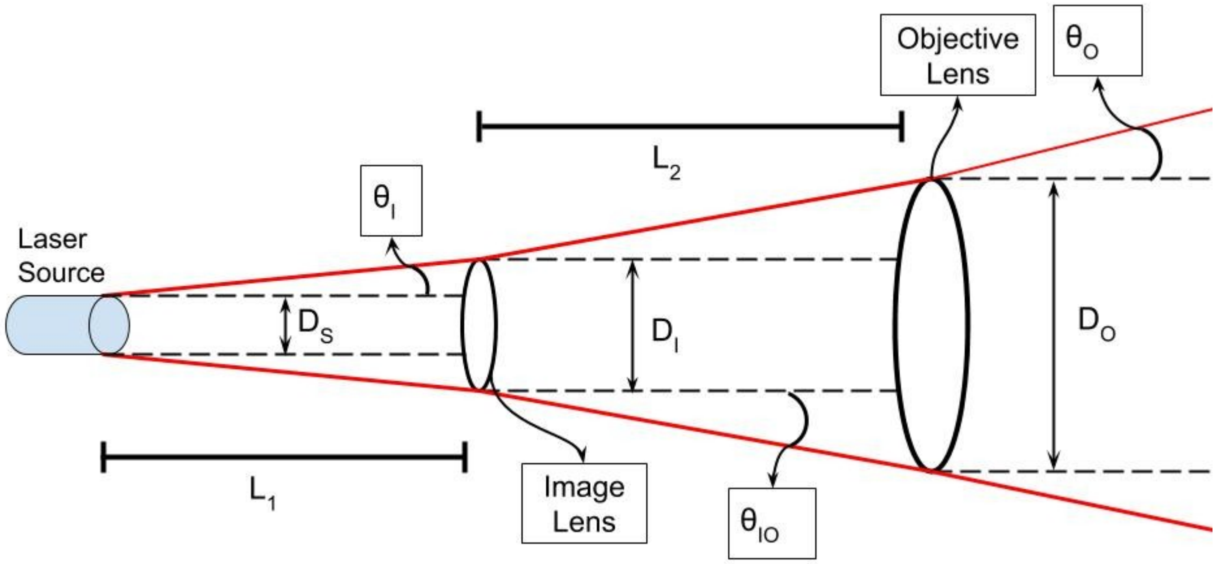


When choosing a scanning method for the LiDAR, the Palmer scan pattern was decided on due to its ease of fabrication and affordability. Rotating polygonal, and even cubic, mirrors were expensive and even buying multiple smaller mirrors to make our own rotating polygonal/cubic mirrors were more expensive than buying a single mirror. The fiber scanner involved the extra cost of the fibers which also made it a more costly option. The Oscillating mirror scan would require the same mirror that the Palmer scanner would use so it was a viable option in terms of price. The Palmer scanner would be easier to work with though since it can be set to a constant rpm. This makes it easier to obtain the laser pulse direction by comparing the time of a laser pulse to the amount of time that has elapsed since the mirror had begun rotating.

Galilean Beam Expander

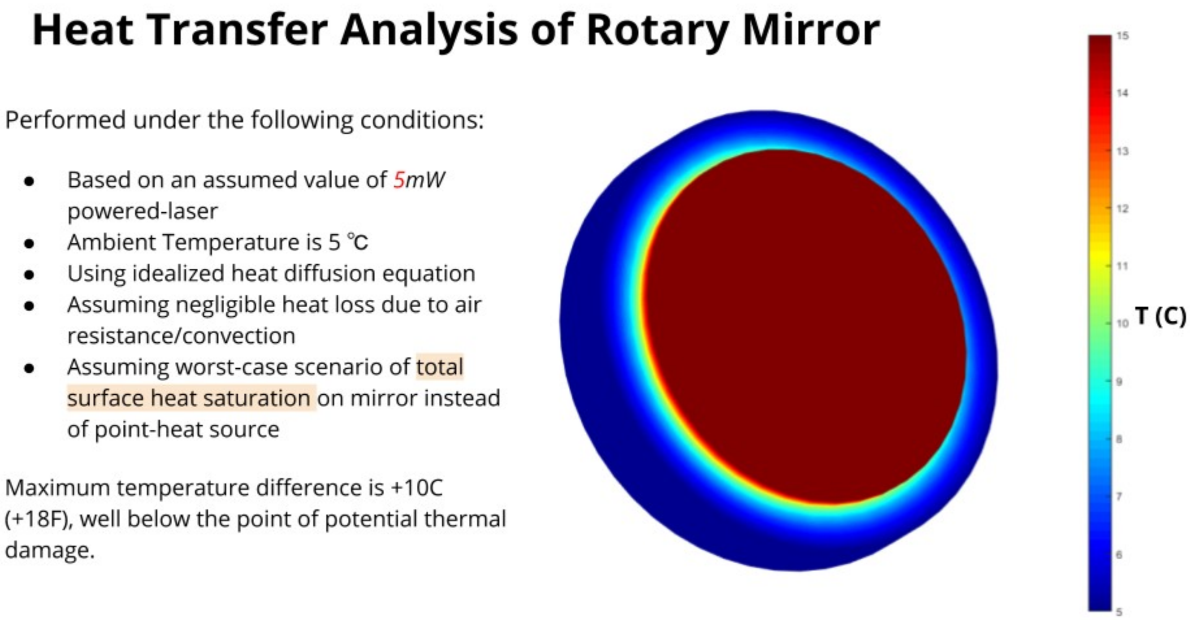


To control beam divergence to be within optimal range, the Galilean beam expander will be employed. This can be achieved by controlling certain laser parameters, namely the output beam diameter, as can be seen in the equation: $\frac{D_O}{D_I}=\frac{\theta_I}{\theta_O}$ where D_O is the beam's output diameter, D_I is the beam's input diameter, θ_I is the input beam divergence, and θ_O is the output beam divergence. If the laser has a set beam divergence then the output beam divergence can be changed based on the distance the image lens is from the laser source and the distance between the objective lens and the image lens.



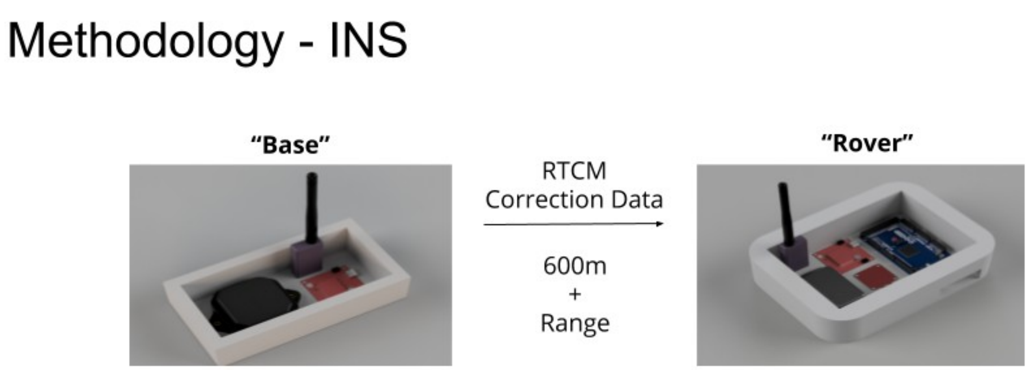
The distance between the image lens and the laser source determines the input diameter following the equation: $D_I = D_S + L_1 \tan(2\theta_I)$ where D_I is the beam's input diameter, D_S is the laser source diameter, L_1 is the distance to the laser source, and θ_I is the input beam divergence. The distance between the objective lens and the image lens can be used to calculate the output diameter following a modified version of the previous equation: $D_O = D_I + L_2 \tan(2\theta_{IO})$ where D_O is the output diameter, D_I is the input diameter, L_2 is the distance between the objective lens and the image lens, and θ_{IO} is the beam divergence angle produced by the image lens.

Mirror Heat Transfer



A heat transfer analysis on a rotary mirror set at 5^{o}C was conducted as a reference point for potential spring temperatures in Northern Texas. Further analysis will be necessary with warmer temperatures for Southern Texas. Much colder temperatures will be required for Alaska but since it will be very cold the analysis probably won't be necessary.

Base Station Antenna



A larger antenna for the base station is currently being looked into. This will be used to match the range that it's able to communicate with the rover to that of the Drone's range. The base station doesn't have the same set of constraints as the rover since it can be used in a vehicle. It won't need to conform to any weight requirements or take the temperature into account (just turn on the heater if it's too cold or AC if it's too hot). A larger antenna could be placed outside of the vehicle, possibly on the roof, for further communication range. One of the Remote Sensing teammates are planning to get a Ham license over winter break to legally operate the base station.

Critical Interfaces

Interface Name	Brief Description	Potential Solution
TRANS/REC	Transmitter laser pulses bounce back to receiver.	Fire transmitter at known region and monitor receiver input
TRANS/REC/SYNCH	Synchronizer controls and time stamps transmitter and receiver	Transmitter & Receiver connected to Synchronizer
M600/ARD	Arduino microcontroller is mounted to the drone and needs protection from the elements.	The Arduino will be in a protective case mounted on the Matrice 600 drone with screws.
RTK/ARD	GPS-RTK2 requires 5V or 3.3V, logic is 3.3V. GPS-RTK2 draws 35mA.	A 3.3V regulator can regulate the 5V USB to 3.3V.
ARD/POW	Arduino requires 5 - 12 [V] of power. Seperate power supply connected to Arduino.	Can use voltage regulator to get desired voltage for the Arduino.

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Requirement Verification Table

Requirement	Verification Method	Description
Emit/receive 1064 nm and 532 nm laser pulses	Test	Will fire laser at a surface with the receiver aimed at the surface to generate data.
System is under 4 kg	Inspection	Weigh the system
Synchronizer controls & time stamps laser pulse generation	Test	Connect laser and receiver to synchronizer
Data can be used to make accurate maps	Analysis	Run data generated through algorithms and input them into a mapping software
Data generated must be saved to flash drive	Test	Run device and check SD card afterwards
Must have two way communication between LiDAR and ground station	Test	Send data to LiDAR from ground station then check SD card

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Risk Assessments

Avionics Risk Assessment

Severity						
	5					
	4		AVI-2			
	3	AVI-3	AVI-1			
	2					
	1					
		1	2	3	4	5
		Likelihood				

Risk ID	Severity	Likelihood	Risk Rating	Description
AVI-1	3	2	6	Communication error between microcontroller and connected components
AVI-2	4	2	8	Electronics get too cold and can cause sudden failure for the entire payload system
AVI-3	3	1	3	All electrical components and wires become disorganized and shifted in-flight

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Risks - Receiver System

	Description
RS1	The amplifier will amplify any noise present in the received signal. This will produce a distorted output. This situation will be tackled by using filters that will filter out unwanted frequencies.
RS2	If light is reflected at an angle back to the receiver (due to hitting uneven ground surfaces), the output signal produced will be smeared and produce faulty altitude readings.
RS3	Diodes are sensitive to temperature changes. Voltage will change with changes in temperature since for diodes the voltage is proportional to the temperature. This scenario will mainly affect the photodiode being used.
RS4	Time delays caused during receiving data will produce faulty output.

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Risks Assessment - Receiver System

Severity						
	5					
	4		RS1			
Severity	3				RS3	
	2					RS4
	1					RS2
		1	2	3	4	5
		Likelihood				

Likelihood	severity
Very rare, < 25% certain	Minimal
> 25% Certain	Mission delay or minor effects
> 50% Certain	Significant reduction in capability
> 75% Certain	May cause failure
> 90% Certain	Total Mission Failure

Risks - Transmitter System

	Description
TS1	Laser Diodes are sensitive to current. Any shifts in drive current will alter the devices' wavelength and output power. Any instability in the drive current caused by noise, drift or induced transients will affect the laser diode's performance characteristics such as the output power and voltage.
TS2	Temperature of diode junction is directly affected by current. Current instability of the source will cause junction temperature swings resulting in different output characteristics for the laser diode. The power values and wavelength will be affected the most.
TS3	Laser diodes require 1.5 V of power but cannot receive that from a bench-top voltage source. Voltage sources cannot control current which affects the diode functionality since they require a constant current. This in turn might create further instability in the wavelength. Voltage sources pose the risk of experiencing thermal shock and/or transients due to a quick change in current.

Risk Assessment - Transmitter System

Severity						
	5			TS3		
	4		TS1			
	3					
	2					
	1	TS2				
		1	2	3	4	5
		Likelihood				

Likelyhood	severity
Very rare, < 25% certain	Minimal
> 25% Certain	Mission delay or minor effects
> 50% Certain	Significant reduction in capability
> 75% Certain	May cause failure
> 90% Certain	Total Mission Failure

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LiDAR Requirements/Parameters

	Min	Prefered	Max	Units
Wavelength	532	X	1064	nm
LiDAR Distance	25	50	100	m
Distance (ft)	82	164.4	328	ft
Scan Distance	26.6	53.2	106.4	m
Scan Dist. (ft)	87.3	174.5	349.1	ft
Pulse Repetition Frequency	5	Depends on recording speed and power consumption	150	kHz
Voltage Consumption	5	5	25	V
Beam Divergence	0.1	0.5	1	mrad
Power consumption	0.1	0.5	10	W
Operating temp range	-10	-	25	C (celcius)

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