# Data Collection Procedure

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## Purpose:

I will collect data to determine consistency of lidar points to better understand how different factors affect reduction in lidar returns.

Note- there are two main applications of lidar:

1. One which has existed for a while (1960's/70's) is airborn lidar, which collects data from the belly of a plane looking down to gain information of the landscape or terrain of a location for agricultural, military, or mapping data. Much of the existing published data is in this area.

2. Autonomous vehicles and robotics. This is a newly growing field, and this is the perspective I am looking to model my data based on. Proximity and orientation are vastly different than the first scenario.

## Github Link

All work and code will be uploaded here: https://github.com/kstisser/LidarAnalysis

## Lidar Wavelength:

Intel Lidar Wavelength: 860nm
• Normal lidar wavelengths:
• infrared (1500 – 2000 nm) for meteorology – Doppler LiDAR
• near-infrared (1040 - 1060 nm) for terrestrial mapping
• blue-green (500 – 600 nm) for bathymetry
• ultraviolet (250 nm) for meteorology

## Factors to Test:

### Discrete

| | | | | |
|---|---|---|---|---|
| Temperature | Ambient | 104(F)/40(C) | 113(F)/45(C) | 122(F)/50(C) |
| Color | Black | Rose Gold | Blue | Silver |

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|---|---|---|---|---|
| Size (x,y,z)(mm) | 40mm^3 | 60mm^3 | 80mm^3 | 100mm^2 |
| Distance | 1m | 1.2m | 1.4m | 1.6m |
| Light | on (day) | off (day) | on (night) | off (night) |

### Continuous

| | |
|---|---|
| Fog | undetermined (need to experiment with bathroom w/and w/out shower on) |

# Procedures:

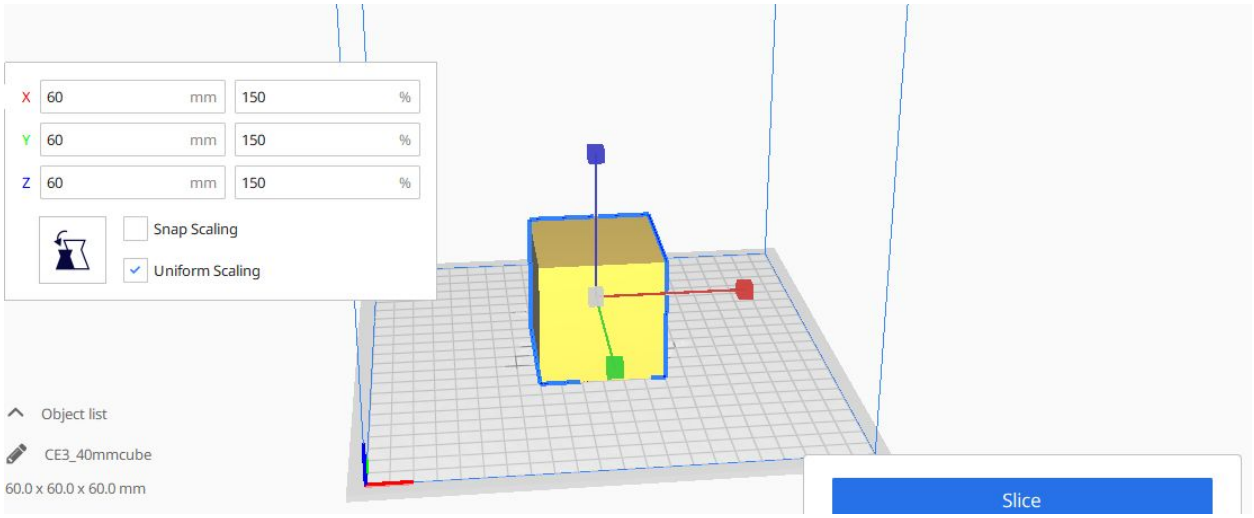
There will be two collection cycles.

## Cycle 1 (Color, Distance, Light):


Objects used: 4 different colored AllSeasons handheld hand warmers on black same PLA printed stand to regulate position/orientation
Procedure:
Record:

* For each distance:
- For each hand warmer of a different color:
  - For each temperature Ambient, 40C, 45C, 50C hand warmer temperature setting
    - For each light setting
      - Record data while changing fog from none to completely on with hot water(10 minutes)

## Cycle 2 (Size):




Objects used: 4 PLA 3D printed hemispheres scaled at x1, x2, x3, x4
Procedure:
Record:
* For each distance:

- For each size
    - For each light setting
        - Record data while changing fog from none to completely on with hot water(10 minutes)

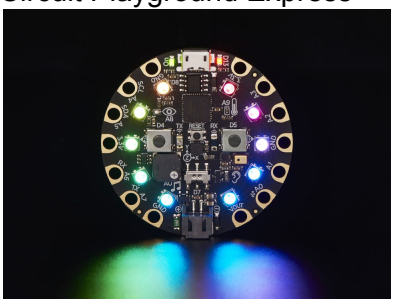
In post processing (Both Cycle 1 & 2):

- Filter all data outside a 2" buffer window of expected location and size
- Record data for each variation in the matrix
- Plot data
- Fit best line to approximate relationship between different varying factors and number of lidar points
- See if there are any trends

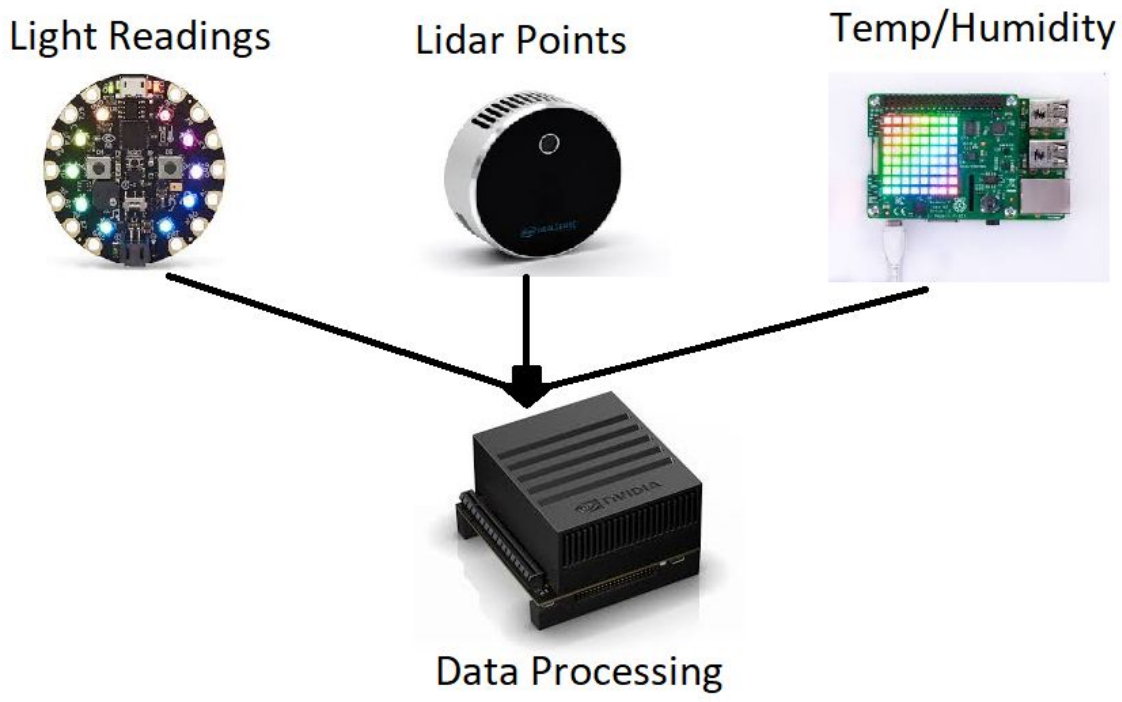
Overall objective: Try to get relationships and come up with model

# Hardware Plan

| Device | Purpose | Link |
|---|---|---|
| Intel® RealSense™ LiDAR Camera L515 | Lidar transmission and collection | https://www.intelrealsense.com/lidar-camera-l515/?cid=se |

| | | |
|---|---|---|
|  | | m&source=sa360&campid=2020_q1_egi_us_ntgrs_nach_revs_text-link_brand_exact_cd_realsense-l515-lidar_o-1lngr_google&ad_group=lidar&intel_term=intel+lidar&sa360id=43700050730407521&gclsrc=aw.ds&&gclid=Cj0KCQjwtZH7BRDzARIsAGjbK2ZNq2p_2Q2n2j2nshL3-X5qpAgG6vv4nLJ5-CrenwGsGU3eOlZSd7YaAko9EALw_wcB |
| Circuit Playground Express  | Light sensor data collection | https://www.adafruit.com/product/3333 |
| Raspberry pi 3 with Sense Hat  | Fog approximation with temperature/humidity readings | https://www.raspberrypi.org/products/raspberry-pi-3-model-b-plus/<br><br>https://www.raspberrypi.org/products/sense-hat/?resellerType=home |
| Xavier  | This would handle processing lidar points and will be time synchronized and on the same network as the raspberry pi. Data collection, accumulation, and processing will be done on this. | https://developer.nvidia.com/embedded/jetson-agx-xavier-developer-kit |

# Data Flow Diagram




# Code Segments

| | |
|---|---|
| Data Collection | - Collects temp/humidity from the pi and determines a fog level<br>- Collects light reading from the Circuit Playground Express<br>- Collects the lidar points<br>- Does a time synchronization between the three types of data<br>- Handles incoming arguments on start for static parameters (ie size, color, etc.)<br>- If time permits, processes all data in a Kalman Filter |
| Post processing cleanup | Filter lidar points so the data only includes largely points on the object, and not the whole room (this could be adjusted to be in the data collection piece, which would make kalman filtering easier, but locations would have to be precise) |
| Post processing analysis | This will largely include line fitting, or possibly unsupervised machine learning techniques to find patterns in the data, which will be used to formulate the model |

# Data Aiming to Obtain for the Final Paper

- **A model** for projecting accuracy/consistency of number of lidar points that includes the relationships between different factors based on the experiments. If some factors have no effect, they will be dropped and not brought into the model. *Include clearly defined variables.*
- **Analytic Analysis of the model**:
    - Equilibrium solutions
    - Classifying solutions by stability criteria
    - Display qualitative phase space information
- **Simulations**- simulate how these factors would relate in certain scenarios on a more dense lidar for more practical scenarios. (Stencils VL16 & VL32 Kaarta Lidar systems) (Hot sunny day, warm night, foggy day, etc.)
- **Conclusions-** Are there certain factors that degrade the lidar so much that you may need to take secondary measures rather than just relying on the lidar, like radar, and what are they?

# Known Vulnerabilities

* The Intel Lidar, while cost effective, is intended largely for indoor use, and may not translate as easily towards outdoor intended lidars.
* Movement of either the sensor or the object being sensed will drastically complicate the initial model, but hopefully this is a start

# Other Factors Not Taken Into Consideration

* Movement of either sensor or object
* Material of the object
* Density of the object (bush or fence lidar can pass through)
* Don't consider potential for echos in returns (explained in 1st paper below)

# Existing Modeling Papers

| | |
|---|---|
| https://arxiv.org/pdf/1907.07748.pdf | - Autonomous vehicle application<br>- Deep Neural Network to model echo pulse widths learned from real data using Polar Grid Maps (PGM)<br>- used simulation to generate noisy lidar data for training<br>- trained DNN reinforcement learning model<br>- Are proposing method for migrating from using simulated data to real data |

| | |
|---|---|
| | - 2 histograms used:<br>  * one for EPW values per echo and object materials<br>  * the other one is the probability of echos occurrence over different yaw shooting angles<br>- Used 2 layer DNN:<br>  * 1st layer used CNN that interferences EPW values based on polar grid map approach<br>  * 2nd layer uses a selection block that best represents the ray profile of the many discrete signals for each echo (up to 3)<br>- Used U-Net architecture to use data with 2 channels, and data goes through an encoder of 3 down-sampling blocks (each with 2 convolutional layers, 3x3 kernels), then a transpose convolutional layer. The output represents a PGM of 1 channel of EPW info for the full scan<br><br>Note- a Polar Grid Map (PGM) is a full 3D lidar scan in a 3D tensor (input data to the DNN) |
| https://www.researchgate.net/publication/259638395_Mathematical_modelling_applied_to_LiDAR_data/link/5950be42a6fdccebfa6c57f5/download | - Airborn application measuring height of vegetation to obtain topological mapping for forestation in China<br>- Triangulated Irregular Network (TIN) structure was applied to model the relief of the area<br>-  Canopy height model (CHM) was also calculated to obtain bare soil, shrub and tree vegetation mapping in the study area.<br>- Extra processing done for circular plot measurements to compare biomass estimates and the lidar height data<br>- Many techniques used based off morphological filters what involved selecting minimum or maximum values for a specific location<br><br>Step 1. Made Digital Elevation Model (DEM), a continuous mapped model of the land<br>  (Data can be stored either in XYZ plotted triangles- Triangulated Irregular Network (TIN), or as elevation values- Raster)<br>Step 2. Took smaller and smaller regions to eliminate non-ground values by finding min |

| | value |
|---|---|
| https://ieeexplore-ieee-org.ezproxy.neu.edu/document/8296502 | - This was more of a method of obtaining objects using lidar points, and focus on the algorithm rather than the model<br>- used a linear model with added gaussian noise |

# Reference Documentation

| Site | Used For |
|---|---|
| https://learn.adafruit.com/adafruit-circuit-playground-express/playground-light-sensor | Code referenced for obtaining light reading for circuit playground express |
| https://arcanesciencelab.wordpress.com/2019/08/05/working-with-the-adafruit-circuit-playground-express-using-the-raspberry-pi-4-part-4/ | Code referenced for obtaining light reading on the raspberry pi |
| https://www.kaarta.com/products/stencil-2-for-rapid-long-range-mobile-mapping/ | More advanced lidar systems |
| http://web.pdx.edu/~jduh/courses/geog493f12/Week04.pdf | Extra data on lidar |