

Department of Geomatics Engineering

ENGO 500 – Capstone Project

Aerial Photogrammetry and Modelling of the Calgary Zoo

Prepared for Dr. Steve Liang

Prepared by Team ZooOGL

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Executive Summary

This report proposes the ideas and methods of a design project that will develop a detailed 2D map of the Calgary Zoo for OGL Engineering. Firstly, we will perform a camera calibration to ensure that the equipment parameters are well defined for the photogrammetric data collection. Then, we will design a ground control network which will allow for high precision data adjustment, and craft a flight plan for aerial image collection. Additionally, a ground survey of the chosen control points will also be performed in order to define our photogrammetric datum.

There is lots to see and do at the Calgary Zoo, and it is easy for those unfamiliar with the layout to waste time wandering around in an attempt to find their way. By starting with the high-resolution aerial images collected with the help of OGL Engineering, we will construct a 2D map containing all relevant information that a Zoo guest could possibly need. From the location of the nearest restroom, to the scheduled times for the gorilla feeding, our map will provide that information. Helpful infographics will provide detailed information about the animals as visitor's journey around the zoo. Furthermore, the LiDAR data will help produce a 3D model of the Zoo's buildings as well as generate a DEM to mitigate flood impacts should the Bow River flood.

By providing OGL with an updated DEM of the zoo and surrounding areas, the impact of environmental hazards such as floods can be mitigated through early warning systems to evacuate exhibits and residential areas at lower elevations next to the river.

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List of Abbreviations

AOI	Area of Interest
ALSA	Alberta Land Surveyors' Association
ASCM	Alberta Survey Control Marker
DEM	Digital Elevation Model
DSM	Digital Surface Model
EL	End Lap
EOP	Exterior Orientation Parameter
GCP	Ground Control Points
GIS	Geospatial Information Systems
GSD	Ground Sample Distance
IOP	Interior Orientation Parameter
LiDAR	Light Detection and Ranging
MMSS	Mobile Multi-Sensors Systems
NTS	Not To Scale
SL	Side Lap
UofC	University of Calgary
UCEE	University of Calgary Engineering Endowment

1 Introduction

1.1 Project Identification

Table 1: Project Identification

Project Identification			
Project Name:	Aerial Photogrammetry and Modelling of the Calgary Zoo	Project Start Date	September 11, 2018
Forecasted Total Project Cost	\$53441	Project End Date	April 19, 2018
		Project Duration	8 months

1.2 Project Description

The aim of the project is to capture aerial photographs of the Calgary Zoo and the surrounding areas. A detailed map and 3D model of the Calgary Zoo will be developed with the data collected. This is a joint project with OGL Engineering who will provide the aerial photographs of the zoo.

The scope of our project entails a variety of ground work and software analysis based on photogrammetric network design and evaluation. A flight plan will be designed to maximize coverage of the Zoo and the surrounding areas at the specified ground sample distance (GSD) while minimizing fuel cost by determining the optimal number of flight lines for capturing images. The ground work will include a camera calibration to ensure that the equipment parameters are well-defined for the photogrammetric data collection, followed by a ground survey of the chosen control points to define our photogrammetric datum. The latter will be performed after the images have been captured in order to establish control within the images based on network design principals to determine the photo-identifiable ground control points, tie points and check points. Various software will be used to process and analyze the images such as Trimble Inpho UASMaster and Geomatica. Extraction of image parameters will be performed in mapping software to generate a map as well as a digital elevation model (DEM) that can be used to mitigate flood impacts. This will also be developed using our own code along with open source software for image parameters extraction and processing LiDAR data to generate a 3D model our project's area of interest (AOI) i.e. the Calgary Zoo. The AOI for this project is shown below in Figure 1 and outlined by a blue boundary with the Calgary Zoo located in the middle.

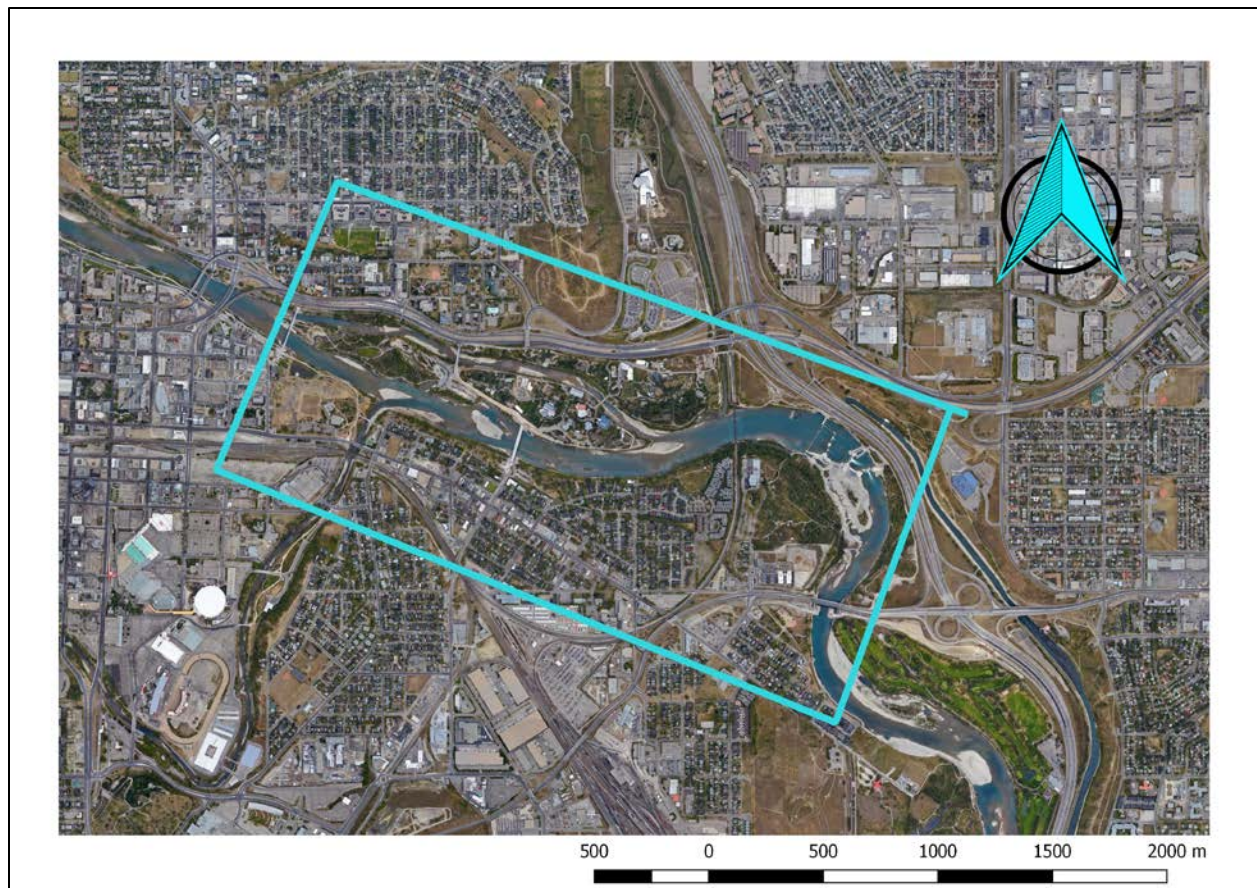


Figure 1: Area of Interest (AOI)

There are many attractions at the Calgary Zoo and it can be difficult for visitors to view each exhibit if they are not familiar with the layout of the zoo. To address this problem, high-resolution aerial images and aerial LiDAR can be used to produce georeferenced maps such as an orthomosaic photo, a digital elevation model (DEM), and a digital 3D model containing the main Calgary Zoo buildings; this would allow visitors to have a fun and interactive way of exploring the zoo. From locations of the nearest restrooms to the scheduled times for the panda feeding, our map will provide information for the zoo visitors whereas the 3D model and DEM will aid the Calgary Zoo and the City of Calgary develop mitigation strategies in case of environmental hazards such as floods.

1.3 Impact if not done

During the heavy rainfall and flood of 2013, the Bow and Elbow rivers exceeded their expected water level and overflowed their bank at a rate of 1800 cubic meters per second, flooding most of the city, nearby parks and the Calgary Zoo. With only a few hours to evacuate 200 animals, the Calgary Zoo staff relied on digital elevation models (DEMs) provided by the City of Calgary to evacuate areas of lower elevations with the closest proximity to the river before evacuating the remaining animals. Fortunately, most animals survived demonstrating the importance of updating topographic maps and elevation models to mitigate environmental hazards.

By taking on this project, our group hopes to combine our skills and knowledge to update and improve the map and DEM of the Calgary Zoo as well as the surrounding areas near the Bow River to allow easier and quicker evacuation and to minimize economic costs should future environmental events occur.

1.4 Proponent Profile

As part of the Geomatics Engineering Capstone projects, groups of three to four students undertake a design project related to their field of interest within Geomatics Engineering. Our team, ZooOGL, is the largest group within our class, consisting of six dedicated and innovative Geomatics Engineering students.

Although our team members have all taken the same core courses within their Geomatics Engineering degree, each of us have preferences and areas of interest ranging from remote sensing, survey law and photogrammetry, which allowed us to undertake such a large project. Furthermore, our technical background in spatial data analysis, surveying, information systems as well as land development and planning will help us undertake any data-related challenges ranging in any of those attributes.

Additionally, our team has a strong background in communications especially having done courses such as rhetorical and technical communications as well as formal technical reports for various assignments which will help in our analysis and execution of the project's development.

Since the scope of the project has expanded from producing a simple interactive map of the Zoo and developing a GIS database to generating a 3D model and DEM of the zoo, we feel that our different skills and areas of interests could be utilized in a more engaging and effective manner by forming a larger group thus contributing to a greater product.

1.5 Collaborator Profile

As part of each Capstone project, a supervisor i.e. a professor within the field of study of the project is needed to guide and provide feedback to their group to ensure the project is feasible, meets the requirements and troubleshoot any issue related to the content of the project. Based on this, we are honored and humble to be able to work with Dr. Naser El-Sheimy as our supervisor who is a professor and former Head of the Department of Geomatics Engineering at the University of Calgary. He has 30 years of experience in Geomatics Engineering and his research expertise includes Geomatics multi-sensor systems, GPS/INS integration, mobile mapping systems, digital photogrammetry and their applications in transportation and Geospatial Information Systems (GIS). Due to his vast expertise, credibility and renowned contribution to each of these subjects in Canada and globally, we are humbled to have him supervise us and are sure that that our project can benefit by applying fundamental knowledge from each of those topics to achieve a detailed and reliable orthomosaic map of the Calgary Zoo and produce a 3D model and DEM.

To further assist our team, Hani Mohammed, who is a PhD candidate and researcher working with Dr. El-Sheimy as part of the Mobile Multi-Sensors Systems (MMSS) research group, will work with us and provide advice, feedback, and oversee our project. Hani specializes in estimation techniques, laser scanning, and UAV photogrammetry. Due to his experience and technical knowledge, Hani can help in learning how to use various software to process aerial images and to apply the estimation techniques from photogrammetry to extract the necessary parameters to generate a 2D map and 3D models of the zoo's buildings using the LiDAR data. His contribution will also help him research various GNS/INS integration

for navigation using the trajectory from the flight and how that can affect the location of where the aerial images were captured.

Our photogrammetry project would not have been possible without the help and support of OGL Engineering. OGL Engineering is a Calgary based company providing professional geomatics services to businesses since 1980. The company specializes in collecting high quality spatial data including aerial LiDAR, high resolution ortho-rectified imagery, 3D laser scanning and bathymetry for various clients within Calgary and Canada. Ever since their establishment, they have worked on numerous aerial photogrammetry projects for the City of Calgary and continue to collaborate with them regularly. Their years of experience, equipment and client satisfaction of high quality and detailed geospatial products make them the perfect company to work with and undertake such an intricate yet extensive photogrammetry Capstone project.

1.6 User Profile

The primary user of our DEM and map will be OGL Engineering as part of the requested project deliverables. After completing the project, the DEM and map can be provided to the City of Calgary municipality and the Calgary Zoo. Although this is a joint project with OGL Engineering who will capture the aerial images for our team, our team's responsibility will be to process and analyze the data to produce an orthomosaic photo, a map, and a DEM using the LiDAR data processing as part of the photogrammetry learning experience for our Capstone project. Fortunately, all group members are currently enrolled in the 'ENGO 531: Advanced Photogrammetry' course and have a good understanding of what is expected to generate those products with detail and precision based on ground control surveying and software analysis. Furthermore, this will also provide OGL Engineering with an updated map of the Calgary Zoo and surrounding areas to keep for reference and provide to clients if feasible.

Also, the Calgary Zoo are the primary beneficiaries of our project due to several reasons. Currently, the Calgary Zoo map is not user-friendly and lacks the aesthetics and information to aid users to find their way to the exhibits easily. The high quality orthomosaic will help generate a more detailed map for the zoo to allow users to easily find the relevant information for exhibits and directions. These photos will also provide updated location and design of features such as walking paths, garbage bins, building and exhibits which will be generated after completing the ground control survey to locate those features from the captured images.

Furthermore, the generation of a DEM will benefit both the City of Calgary and the Calgary Zoo by reducing the impact of future floods events by allowing early evacuation of personnel and exhibits near the river, i.e. at a lower elevation compared to the rest of the zoo. DEMs can also help Engineers design walls or embankments near rivers to control the water level; this can minimize economic costs, reduce potential damage, and allow constant monitoring of the river's discharge rate in the event of environmental hazards.

For this project to succeed, constant communication and feedback will be needed from OGL Engineering to design a map that meets their needs while maintaining a high standard of cartographic communication. This map will be refined to be intuitive and aesthetically pleasing for all visitors to use. In order to mark

certain features of the map, permission will be needed from the Calgary Zoo for our team to obtain the measurements quickly without disrupting any events and exhibits.

2 Objectives

The overall objective of this project is to capture aerial photos of the Calgary Zoo and the surrounding areas and analyze them to produce a map and DEM for OGL Engineering that can benefit the Calgary Zoo and the City of Calgary. A flight plan will be done to determine the number of flight lines required to achieve the necessary ground sample distance. This will improve the efficiency of image acquisition, and ensures that the specified ground sample distance can be achieved above the minimum safe flying height. Afterwards, a ground control survey will be performed to identify multiple ground control points (GCPs) and check points which will also be identified in the images for georeferencing. Furthermore, the fundamentals of photogrammetry will be applied to calibrate the camera by performing a bundle adjustment to estimate the internal camera parameters, the intrinsic parameters, and the 3D object space coordinates of the tie points. With the coordinates of the tie points, a 2D detailed and aesthetic map of the Calgary Zoo will be created along with a georeferenced orthomosaic photo. Lastly, a DEM and 3D model of the Calgary Zoo buildings will be made using the LiDAR point cloud after data classification. Due to the scope of the project and the course requirements that must be fulfilled, a series of small accomplishable goal have been created to ensure that the project team can remain on track to fulfill the overall objective of this project, this is highlighted in below in section 2.1 and 2.2.

2.1 Objectives, Outputs, Outcomes and Criteria

To accomplish the objectives of this project, the following goals must be achieved as shown in Table 2.

Table 2: Project goals with expected outcomes, outputs and their measurement criteria

Item	Project Objectives	Project Outputs	Project Outcomes	Measurement Criteria
1	Design flight plan	Flight Trajectory, aerial images and LiDAR data of the AOI	Optimal flight lines and minimal flight time to reduce data acquisition cost	Ground sample distance of 5cm
2	Ground Control Survey	3D coordinates of check and control points to be used in calibration procedure	<ul style="list-style-type: none"> - Develop surveying skills using RTK - Follow best standards and practices to ensure minimal errors in data 	<ul style="list-style-type: none"> - Accuracy of the surveyed 3D coordinates - Distribution of the selected points - Geometry of network
3	Use automatic software for Camera Calibration – Bundle Adjustment	EOPS, IOPS, camera and intrinsic parameters from	Apply theory from photogrammetry to calibrate camera and reduce errors in the	Accuracy of the camera calibration results

		bundle adjustment	measured image locations of check and control points	
4	Classify and process LiDAR data	- Generate bare Earth point cloud - 3D model of the zoo's main buildings	Become familiar with analyzing LiDAR data and point cloud classification	Sufficient density to create a 50cm DEM grid
5	Create DEM and DSM	- Generate DSM and DEM	Predict and mitigate flooding impacts of the Bow and Elbow rivers	Accuracy of the DEM and DSM gridded at 50cm
6	Create Orthophotos	- Ortho-rectified photographs	Orthophotos prepared for mosaic	Relief displacement minimized
7	Mosaic Orthophotos	- Ortho-rectified photo of AOI	Orthophoto mosaic ready to use for mapping	Relief displacement minimized
8	Map Generation	Improved 2D/3D map with more information, features and visual appeal	- Cartographic design and communication - Develop proper standards and practices related to map design and geospatial information	- Consistency with existing maps in terms of main features and reference frame - Cartographic design and communication - Constraints and map compositions
9	Fulfill ENGO 500 requirements	Proposal, Progress Reports and presentations	- Apply technical knowledge in class to a real-world Engineering project. - Develop technical report writing skills - Develop communication skills and collaboration with various stakeholders	Feedback from graded reports

2.2 Project Performance Measurement Plan

The performance measurement plan for each of the objective listed above are shown from Table 3 to Table 11 below.

Table 3: Performance measurement for Flight Plan Design

Design a flight plan	
Description of Measure	Method
How does it relate to program objectives	An optimal flight plan will minimize the project budget and acquire sufficient data for the following objectives
Method used to measure	<ul style="list-style-type: none"> - Full ground coverage and minimum economic cost - Meet the ground sample distance specifications
Responsibility: who measures/analyses/reports	OGL Engineering and ZooOGL
Frequency of measure	Once
Key targets	5cm ground sample distance
Reporting on results	Estimated and actual flight plan costs, progress report

Table 4: Performance Measurement for Gound Control Survey

Ground control survey	
Description of Measure	Method
How does it relate to program objectives	Accurate and well-distributed control and check points will increase the accuracy of the following tasks
Method used to measure	<ul style="list-style-type: none"> - Assess type, location and frequency of the selected points in the aerial images - Compare measurements to a minimum of 3 ASCM coordinates - Check instrument specifications for measurement precision
Responsibility: who measures/analyses/reports	ZooOGL
Frequency of measure	Once
Key targets	Ensure well-distributed control and check points. Follow proper survey procedure to reduce measurement errors.
Reporting on results	Ground control report, progress report

Table 5: Performance Measurement for Camera Calibration

Camera calibration	
Description of Measure	Method
How does it relate to program objectives	Accurate camera IOPs will reduce the errors in the estimation of tie point 3D coordinates
Method used to measure	Compare the obtained principle point offset, focal length, radial lens distortion parameters and de-centering lens distortion parameters with the nominal values
Responsibility: who measures/analyses/reports	ZooOGL
Frequency of measure	Once
Key targets	Apply augmented collinearity equations as functional models and complete a bundle adjustment
Reporting on results	Camera calibration report with the updated IOPs and recommendations, progress report

Table 6: Process LiDAR Data

Process LiDAR Data	
Description of Measure	Method
How does it relate to program objectives	Classified LiDAR data is used to identify ground features and generate DEM and DSM
Method used to measure	Point density of classified LiDAR data
Responsibility: who measures/analyses/reports	ZooOGL
Frequency of measure	Once
Key targets	<ul style="list-style-type: none"> - Identify ground features using the LiDAR data and compare classified ground features with the images - Assess the point density of the classified data
Reporting on results	Progress report

Table 7: Create DEM and DSM

Create DEM and DSM	
Description of Measure	Method
How does it relate to program objectives	Final products of entire project
Method used to measure	Precision assessment on DEM and DSM generated by Trimble UASMaster
Responsibility: who measures/analyses/reports	ZooOGL
Frequency of measure	Once
Key targets	<ul style="list-style-type: none"> - Analyze the accuracy of the interpolation method and sampling type for the generation of DSM and DEM - Analyze the accuracy of the noise level
Reporting on results	Progress report, final report

Table 8: Create Orthophotos

Create Orthophotos	
Description of Measure	Method
How does it relate to program objectives	Orthophotos are prepared for the orthophoto mosaic
Method used to measure	<ul style="list-style-type: none"> - Scale of the orthophoto is uniform - Distortion and relief displacement are minimized
Responsibility: who measures/analyses/reports	ZooOGL
Frequency of measure	Once
Key targets	<ul style="list-style-type: none"> Perform ortho-rectification for the aerial photos Minimize relief displacement
Reporting on results	Progress report

Table 9: Mosaic Orthophotos

Mosaic Orthophotos	
Description of Measure	Method
How does it relate to program objectives	Mosaic orthophotos are used for mapping
Method used to measure	Scale of the orthophoto mosaic is uniform Distortion and relief displacement are minimized
Responsibility: who measures/analyses/reports	ZooOGL
Frequency of measure	Once
Key targets	Merge the rectified orthophotos into an orthophoto mosaic
Reporting on results	Progress report

Table 10: Performance Measurement for 2D and 3D Map Generation

Map Generation	
Description of Measure	Method
How does it relate to program objectives	Final product of objective 1 to 3
Method used to measure	- Compare the new map features and coordinate systems with the previous maps and - Define map constraints and propose cartographic design based on the obtained data and user profile
Responsibility: who measures/analyses/reports	ZooOGL
Frequency of measure	As many times as possible
Key targets	- Analyze the existing zoo maps and make improvements - Define purpose, geospatial reality, accuracy of data, scale, users, conditions of use and technical limitations of the map - Achieve visual balance, legibility, visual contrast and hierarchical organization of the map
Reporting on results	Progress report

Table 11: Performance Measurement of fulfilling ENGO 500 course Requirements

Fulfill ENGO 500 requirements		Feedback from graded reports	
Description of Measure		Method	
How does it relate to program objectives		Quality of the project documentation	
Method used to measure		Grades and comments on the proposals, progress reports and presentations	
Responsibility: who measures/analyses/reports		ZooOGL	
Frequency of measure		As many times as possible	
Key targets		Develop project management skills Present and report project processes Update project deliverables	
Reporting on results		Progress report, final report	

2.3 Objective Specifications

The project will be designed and executed in a manner which ensures that the project will meet the precision proposed by the project sponsor, as well as industry accepted best standards.

Table 12: Specifications of different objectives in the project

Project Section		Specifications
Flight Planning		<ul style="list-style-type: none"> - 5 cm ground sample distance - 60% forward overlap of adjacent images - 30% overlap between adjacent flight lines - 1 perpendicular flight line - minimum required flight lines
Ground Control Survey		<ul style="list-style-type: none"> - Performed with Trimble R10s utilizing RTK with a single baseline - 20 mm minimum horizontal precision @ 1σ - 25 mm minimum vertical precision @ 1σ
Mapped Features		- Shapefile format
Orthomosaic Photo		- GeoTIFF format
Bare Earth point cloud		.las format
Digital Elevation Model		<ul style="list-style-type: none"> - Regularly gridded at 0.5m - GeoTIFF format

3 Proposed Methods and Materials

The duration of the project is eight months, from September 2018 to April 2019, and is divided into two 4-month subprojects. The project deliverables for the first subproject are a flight plan for capturing aerial imagery and LiDAR data of the Calgary Zoo and its surrounding area as shown in Figure 1 in the Appendix, a ground control network report with accuracy assessment, camera calibration report on interior orientation parameters, results and analysis of exterior orientation parameters of the aerial imagery, and a zoo map with identified ground features. The project deliverables for the second subproject are an orthomosaic photo of the aerial photos, a bare Earth point cloud from the classified LiDAR data, a bare Earth DEM from the bare Earth point cloud, a full ground feature DSM and a digital 3D model of the main Calgary zoo buildings.

3.1 Flight Plan

The most economical flight plan has a minimum number of flight lines which is designed to be parallel to the Bow River. This is indicated by the green markers in Figure 2 which also indicate the flight trajectory parallel to the Bow River. One additional flight line perpendicular to the project area for calibration purpose is required shown by the red markers. With a 5 cm nominal ground sample distance specification, the scale of the images can be determined. The flight height is defined by the parameters of the camera used to collect the images, as well as the required specifications of the project. The base to height ratio is calculated as 1.01 across track, and 0.76 along track. 60% image overlap within a single flight line, and 30% overlap between adjacent flight lines are required to ensure consistent stereoscopic coverage of the AOI. The number of the flight lines and the number of images in each flight line will be determined. The latitude and longitude of the camera perspective centers of each image will be calculated such that the orientations and distances of each flight line is defined. Some additional images at the periphery outside the AOI will also be captured to ensure full coverage of the AOI.

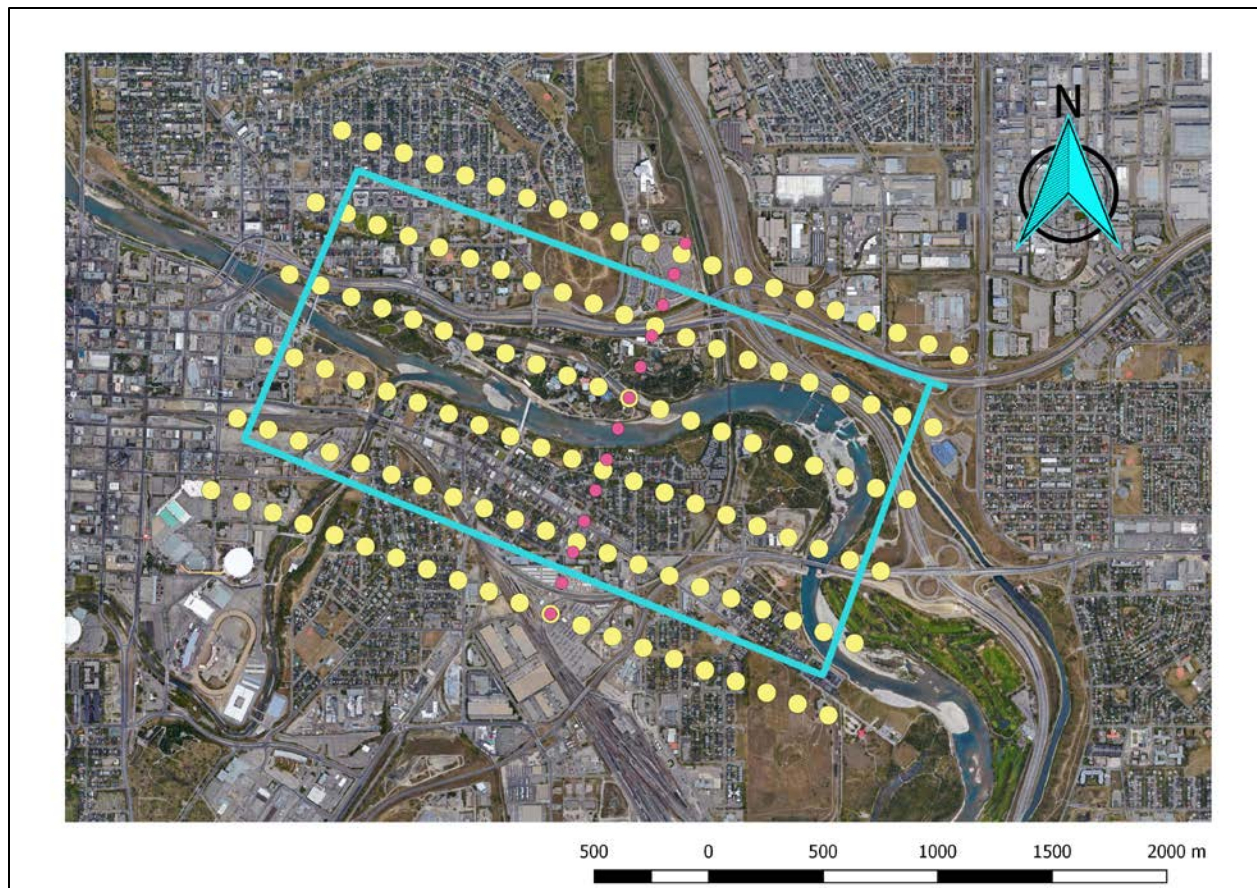


Figure 2. Flight lines and location of image capture points for the chosen AOI

3.2 Aerial Photos and LiDAR data

The aerial photos will be collected using OGL's RCD30 80MP with 53mm focal length, which will be used for selecting photo-identifiable GCPs and check points and generating orthomosaic photo. The flight trajectory, exposure time and time intervals between the capturing of each image will be provided by OGL to determine the approximated EOPs for camera calibration.

Unclassified LiDAR data will be collected along with the aerial images using OGL's ALS70 CM, which will be used for generating bare Earth point cloud, DEM and DSM in the second subproject.

3.3 Ground Control Network

After the photos are captured, a ground control network will be established with well distributed photo-identifiable GCPs and check points. The GCPs may include as many existing ASCMs as possible and must be chosen along the borders of the network with some at the center of the network. The GCPs and check points will be surveyed using GNSS. Tie points for different image features need to be selected and can be selected by an auto detection program.

3.4 Camera Calibration and Bundle Adjustment

The camera used for collecting aerial photos will be calibrated using a bundle adjustment to determine the IOPs, camera intrinsic parameters, EOPs of each image as well as the 3D coordinates of the tie points. Using the GNSS-surveyed GCPs and tie point observations as input, the principle offset, focal length, first two de-centering lens distortion parameters and first four radial lens distortion parameters will be obtained. The accuracy of the camera self-calibration can be assessed by the GNSS-surveyed 3D coordinates of the check points.

3.5 Calgary Zoo Map

With the estimated 3D coordinates of the tie points, a Calgary Zoo map can be generated in ArcGIS. By importing the horizontal coordinates of the tie points into ArcMap, a 2D map can be developed based on the point cloud. Referring to the georeferenced aerial photos or the LiDAR data, by tracing the estimated tie points along the outline of the ground features, multiple layers such as roof layer, vegetation layer, paths and walkway layer, the Bow River layer, bridge layer, etc. can be generated. The final zoo map can be created by combining each layer and selecting appropriate colors and symbols for the ground features. A simplified 3D model could be potentially created in ArcGIS as the height of each tie point is known.

3.6 Orthomosaic Photo

All the aerial photos can be merged into one orthomosaic photo that has true distances, angles and areas and minimize the relief displacement. The aerial photos will be ordered by flight lines and georeferenced using the GNSS-surveyed 3D coordinates of the same GCPs located within multiple aerial photos. This will be created using Trimble UASMaster.

3.7 Bare Earth Point Cloud, DEM and DSM

The LiDAR data will be classified into categories such as bare earth, water, canopy etc. Selecting the appropriate interpolation and sampling type, a full feature DSM at 50cm grid size with the outline of buildings, canopies, bridges, roads etc. can be generated. After removing all features except for terrain and water, the LiDAR data is left with a bare Earth point cloud, and a DEM at 50cm grid size can be generated with only the ground and water features. DSM and DEM for the Calgary Zoo and its surrounding areas will be created using the Trimble UASMaster.

3.8 3D Modelling

Digital 3D models of main Calgary Zoo buildings will be created using the classified LiDAR point cloud.

4 Project Plan

4.1 Project Team and Resources

Table 13: Team ZooOGL description

Name:	Lingyi Cui, Trisha Escorpiso, Tyler Greene, Kristy Guan, Dawood Nadeem, and Steven Schroeder (Team ZooOGL)
Organization:	University of Calgary, Schulich School of Engineering, Geomatics Engineering Department
Role:	Undergraduate Student
Responsibilities:	Flight Planning, Control Network Design, Field Survey (GNSS), camera calibration, GIS database, Map of Calgary zoo, DEM/DSM, ortho-rectified imagery, digital 3D models
Key Skills:	Geospatial data manipulation, acquisition, analyzation, photogrammetry, remote sensing, surveying

Table 14: OGL Engineering Description

Name:	Sam Rondeel, Tammy Smith
Organization:	OGL Engineering
Role:	Production Manager and CEO
Responsibilities:	Aerial imagery/LiDAR acquisition, technical support
Key Skills:	Aerial LiDAR, high resolution ortho-rectified imagery, 3D laser scanning, bathymetry

Table 15: Advisor Profile

Name:	Dr. Naser El-Sheimy
Name:	Hani Mahmoud Mohammed, PhD Candidate
Organization:	University of Calgary – Geomatics Engineering Department – Mobile Multi-Sensor System Research Group
Role:	Supervisor & Graduate Student Liaison
Responsibilities:	Technical advising
Key Skills:	Network with industry, Geomatics multi-sensor systems, GPS/INS integration, mobile mapping systems, digital photogrammetry and their applications in transportation and Geospatial Information Systems (GIS)

Table 16: ENGO 500 Course Coordinator Description

Name:	Dr. Steve Liang
Organization:	University of Calgary – Geomatics Engineering Department
Role:	Course Coordinator
Responsibilities:	Coordinate Capstone groups, ENGO 500, advising on project reports
Key Skills:	Project management, industry knowledge/expertise

4.2 Project Management and Control

Due to the size of our group and project, it is important to develop measures that will ensure effective management and control of the proposed project. A guideline in the form of a contract is used to establish the expectations of each member, including completing their tasks in a timely manner, maintaining sufficient communication, participating in decision making, minimizing potential risks and prioritizing safety. It is also important to allow flexibility in our project scope and expectations; circumstances may change and require the project to be re-assessed.

One way to build a team is to develop and improve the interpersonal relationships between the members and to quickly resolve any possible conflicts. If there was a discontent member or if there were members in conflict, it may slow down or even halt the progress of the project, therefore it is important to maintain a positive rapport between members.

The role of each team member will change week to week, this will allow each member to develop and gain experience in the many fields of the project and it ensures that in the event of a missing member, there will be someone who can take over their part and move the project forward. It is also important for each member to record a summary of their procedures to facilitate passing on their role to other members.

A calendar and ZenHub boards, containing the availability of each member, tasks and their deadlines, will be maintained and used to facilitate arranging meeting times and allocating tasks. This will also be used to track the performance of each member and allows the project manager to provide feedback that will help ensure the quality and advancement of the project.

4.3 Project Implementation Plan

This project involves photogrammetric processes essential to produce high quality 3D models as well as other aerial mapping products. The schedule for our project implementation is displayed in the Gantt Chart shown in Figure 3. The project scope is described in greater detail in Table 17 as a sequence of tasks, each with deliverables and specifications.

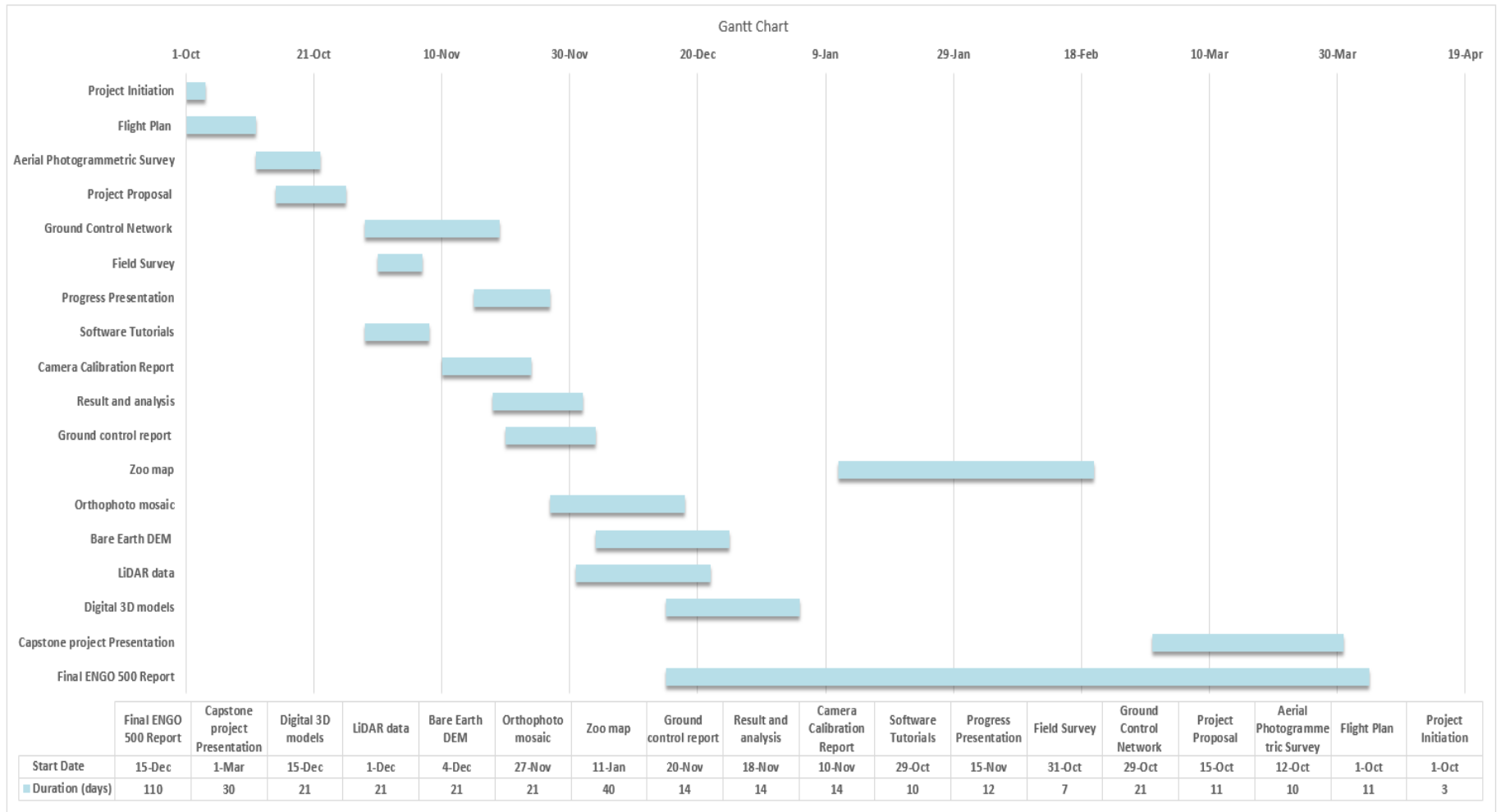


Figure 3. Gantt Chart

Table 17: Work Breakdown Structure of entire project from Fall 2018-Winter 2019

WBS	Task & work breakdown	Duration (days)	Organization	Team Members Name	Days effort/ person	Outputs	Start Date	Delivery Date
1	Project Initiation and Introduction	3			14		10/1/2018	
1.1	Meet OGL representatives, and Project Supervisor team	1	OGL, UofC - Geomatics Engineering department	OGL Representatives, ZooOGL team	7	from OGL to ZooOGL: Project Deliverables		
1.2	Meet OGL Project Supervisor team	2	UofC - Geomatics Engineering department	Project Supervisor team	7			
1.3	Phase 1 completed					Milestone		10/26/2018
2	Flight Plan (Capturing Aerial Imagery and LiDAR data of the Calgary Zoo and its surrounding area)	3	UofC - Geomatics Engineering department	ZooOGL team	18		10/1/2018	
2.1	Design KML file with potential camera image location	1	UofC - Geomatics Engineering department	ZooOGL team	6			
2.2	Calculate flying parameters including flight lines, elevations, EL, SL	1	UofC - Geomatics Engineering department	ZooOGL team	6			
2.3	Calculate the nominal ground sample distance using the appropriate camera specs	1	UofC - Geomatics Engineering department	ZooOGL team	6			

2.4	Phase 2 completed					From ZooOGL to OGL: - KML file with camera locations - Flying parameters		10/10/2018
3	Perform Aerial Photogrammetric Survey	1	OGL	OGL Representatives	1		10/12/2018	
3.1	Acquire aerial imagery, and LiDAR data	1	OGL	OGL Representatives	1			
3.2	Phase 3 completed		OGL	OGL Representatives		From OGL to ZooOGL: - Aerial images - unclassified LiDAR data - Trajectory of flight		10/12/2018
4	Ground Control Network (with accuracy assessment) (Ground control report detailing accuracy of the triangulation)	4.5	UofC - Geomatics Engineering department	ZooOGL team	27		10/29/2018	
4.1	Design Ground Control Network	1	UofC - Geomatics Engineering department	ZooOGL team	6			
4.2	Acquire Tie points/ground control points from imagery	2	UofC - Geomatics	ZooOGL team	12			

	(manual/automated: Trimble UASMaster)		Engineering department					
4.3	ground control network	1	UofC - Geomatics Engineering department	ZooOGL team	6			
4.4	Acquiring ASCM coordinates from SPIN2	0.5	UofC - Geomatics Engineering department	ZooOGL team	3			
4.5	Progress Report	1	UofC - Geomatics Engineering department	ZooOGL team	6		11/19/2018	11/19/2018
4.5	Phase 4 completed		UofC - Geomatics Engineering department	ZooOGL team, ENGO 500 Coordinator		from ZooOGL: - Ground control network design with (control points, check points - monuments) from ZooOGL to ENGO 500 Coordinator: - Progress Report		11/19/2018
5	Ask for feedback and verify results	1	UofC - Geomatics Engineering department	Project Supervisor team	1		11/20/2018	
5.1	Phase 5 completed							11/20/2018

6	Field Survey using GNSS	1.5	UofC - Geomatics Engineering department	ZooOGL team	9		11/21/2018	
6.1	Gaining access to all required location (email appropriate contacts)	1	UofC - Geomatics Engineering department	ZooOGL team	6			
6.2	Reconnaissance		UofC - Geomatics Engineering department	ZooOGL team				
6.3	Transportation of survey equipments		UofC - Geomatics Engineering department	ZooOGL team				
6.4	Perform survey (using GNSS-RTK) will be in groups of two		UofC - Geomatics Engineering department	ZooOGL team				

6.5	Field Calculations							
6.6	Measure ASCM ground coordinates							
6.7	Take a photo of each control and check points (the physical object) during the survey.							
6.8	Progress Presentation	0.50			3		11/27/2018	11/27/2018
6.9	Phase 6 completed					from ZooOGL: - images of the ground points surveyed - coordinates of the ground points surveyed through GNSS		11/28/2018
7	Investigate and learn software's that will be used for for analysis data and	7		ZooOGL team	42		12/17/2018	

	generating results (Trimble UASMaster)							
7.1	Phase 7 completed					from ZooOGL: - have an idea on how to use the software (Trimble UASMaster) for analysing data and generating deliverables		1/9/2019
8	Camera Calibration	1	UofC - Geomatics Engineering department	ZooOGL team	6		1/10/2019	
8.1	Phase 8 completed					from ZooOGL: - Camera calibration report with the updated IOPs and recommendations		1/17/2019
9	Calculate the Exterior Orientation Parameters (EOPs)	1	UofC - Geomatics Engineering department	ZooOGL team	6		1/18/2019	
9.1	Phase 9 completed					from ZooOGL: - Report on the triangulated photo exterior		1/25/2019

						orientation parameters, results, and analysis - CSV format		
10	Ground control report specifying the accuracy of the triangulation	1	UofC - Geomatics Engineering department	ZooOGL team	6		1/28/2019	
10.1	Phase 10 completed					from ZooOGL: - Ground control report describing accuracy of the triangulation		2/4/2019
11	Map of the Calgary Zoo with identified ground features	2	UofC - Geomatics Engineering department	ZooOGL team	12		2/5/2019	
11.1	Phase 11 completed					from ZooOGL: - 2D/3D map with the identified features - shapefile format		2/12/2019
12	Create Orthophotos and Mosaic Orthophotos	2	UofC - Geomatics Engineering department	ZooOGL team	12		2/25/2019	

12.1	Phase 12 completed					from ZooOGL: - Ortho- rectified images - Ortho- rectified images of AOI - GeoTIFF format		3/4/2019
13	Process and classify Lidar Data	2	UofC - Geomatics Engineering department	ZooOGL team	12		3/5/2019	
13.1	Generate bare Earth point cloud from the classified LiDAR data		UofC - Geomatics Engineering department	ZooOGL team				
13.2	Phase 13 completed					from ZooOGL: - Bare Earth point cloud - .las format		3/12/2019
14	Create DEM and DSM	3	UofC - Geomatics Engineering department	ZooOGL team	18		3/13/2019	
14.1	Generate DSM and DEM		UofC - Geomatics Engineering department	ZooOGL team				
14.2	Phase 14 completed					from ZooOGL: - Bare Earth DEM regularly gridded at 50		3/22/2019

						c - GeoTIFF format - Full feature DSM regularly gridded at 50 cm - GeoTIFF format		
15	Digital 3D models of main Calgary Zoo buildings, any CAD format	2	UofC - Geomatics Engineering department	ZooOGL team	12		3/22/2019	
15.1	Phase 15 completed					- Digital 3D models of main Calgary Zoo buildings - any CAD format		3/28/2019
16	Ask for feedback and verify results	1	UofC - Geomatics Engineering department	Project Supervisor team	1		March	
17	Ask for feedback and verify results	1	OGL	OGL Representatives	1		March	
18	Capstone project Presentation	1	UofC - Geomatics Engineering department	ZooOGL team	6		March	
19	Final ENGO 500 Report	2	UofC - Geomatics Engineering department	ZooOGL team	12		March	

4.4 Sustainability

Aerial Images are required every few years in the City of Calgary to ensure that they are always updated. This is used for city planning and land use classification. OGL has previous experience performing airborne photogrammetry for the City of Calgary. Having updated DEMs will ensure that flood risk management will always be up to date with 100-year weather forecasting trends. This will help sustain this project's output for future use.

The Calgary Zoo has been an established company that provides entertainment to a variety of people, and visitors. The protection of the animal exhibits is extremely important for both the animals and investors. That is why this service can be an invaluable resource offered to the Zoo. DEM can be used for long-term water run-off analysis and flood trending.

The Harvey Passage is also located along the river adjacent to the Zoo within the AOI. This passageway is used frequently by white water enthusiasts. It was destroyed in the 2013 flood and was rebuilt with new preventive concrete structures. This area has not been updated with a new DEM either. This work will also ensure the safety of rafters along this region of the river.

Potentially other users along the Bow River would be interested in having their location assessed with aerial imagery and LiDAR.

4.5 Budget

4.5.1 Aerial Photography

The aerial photography will be performed by our sponsor OGL engineering. The cost estimates for the data collection were generously provided by OGL.

Table 18: Data Collection Budget Estimate

Data Collection	Cost
Aircraft Mobilization	\$204
Travel Cost	\$0 – (Project is within Calgary City Limits)
Image Capture Fee	\$1723
Raw Data Processing	\$514
Subtotal	\$2441

4.5.2 Ground Control Survey

The project will require a ground survey to obtain check and control points for the bundle adjustment. This involves researching existing survey control markers (ASCMS) within the AOI, using feature matching algorithms to identify viable points for use, and performing the survey of the selected points.

The required survey equipment is available for use by the students of U of C. Funding to purchase some of this equipment was generously provided by the University of Calgary Engineering Endowment (UCEE).

Table 19: Ground Control Survey Budget Estimate

Ground Control Survey		Hours @ \$100/hr	Cost
Network Design	20		\$2000
Data Collection	80		\$8000
Equipment Charges			\$2000
Materials Charges			\$1000
Subtotal			\$13000

4.5.3 Data Processing

Data processing tasks will make up the bulk of the time invested in this project. These tasks include research, software development, and quality control/assessment of the deliverables.

Table 20: Data Processing Budget Estimate

Data Processing		Hours @ \$100/hr	Cost
Camera Calibration	20		\$2000
Classify & Process LiDAR Data	40		\$4000
Create DEM/DSM	40		\$4000
Create Orthophotos	40		\$4000
Mosaic Orthophotos	40		\$4000
Generate Map	80		\$8000
Subtotal	260		\$26000

4.5.4 Project Administration

The administrative requirements for the ENGO 500 project include a Project Proposal, two interim Progress Reports, as well as a final Project Report.

Table 21: Project Administration Budget Estimate

Project Administration		Hours @ \$100/hr	Cost
Project Proposal	20		\$2000
Progress Reports	60		\$6000
Project Report	40		\$4000
Subtotal	120		\$12000

4.6 Communication and Accessibility of Project Results

After the project has been completed, Team ZooOGL will provide industry standard deliverables to OGL as specified in section 2.3. At this time, it will be decided how much of the project can or will be made available to the public domain using an open source model.

5 Project Issues and Risks

5.1 Issue Identification

The student team will perform most of the project as was laid out in the project deliverables. All team members are required to complete the project in its entirety. Decisions are made by team consensus, and not by a single individual. This allows for diverse team membership and equal engagement. Each team member is responsible for their individual commitment as part of the overall team framework. A team contract is to be in place to ensure project tasks are completed in a reasonable and timely matter.

5.2 Feasibility and Risk

A risk assessment was performed as can be seen in Table 22 below.

Table 22: Risk Assessment

No.	Risk Description	Severity (H/M/L)	Probability (H/M/L)	Mitigation strategies for dealing with each risk
1	Fail to meet user requirements/specifications	H	M	Ensure data will be collected at equal or higher accuracy
2	Fail to collect images/LiDAR data	H	L	Use historical image data, redo flight on a later date
3	Fail to generate an accurate and complete DEM/Map	M	M	Try to achieve the highest level of completeness possible
4	Personnel injury during surveying	H	L	Wearing proper gear such as safety vests. Also, assign a safety supervisor to enforce good standards of practice during field work
5	Availability/loss of qualified personnel	H	L	Rotate jobs, keep personnel updated
6	Bad Weather	L	H	Forecasting, flexibility to move tasks around
7	Loss of data due to hard drive/computer crash	H	M	Frequent and multiple locations of backed data between all group members
8	Scheduling/ deadline completion	H	M	Weekly debriefs, iterative approach

6 Benefits

6.1 Benefits to the public and the Zoo

The Calgary Zoo will be provided with an updated DEM that can be used for flood risk mitigation. This can be used to evacuate the appropriate animals within the flood zone ensuring the safety of the animals.

The Harvey Passage is also located along the river adjacent to the Zoo within the AOI. This passageway is used frequently by white water enthusiasts. Although it was destroyed in the 2013 flood, it was rebuilt with preventive concrete structures to prevent further erosion of the nearby land. Although there is no updated DEM of this area, it will be useful to generate one to monitor the change in the river's flow to ensure the safety of rafters along this region of the river.

6.2 Benefits to collaborators and users

The benefits to the collaborators of the project would be the creativity, combined expertise and knowledge to make a valuable and detailed product which will have a higher impact of usability for the users. Furthermore, collaboration on large scale projects will allow team members to work together on several ideas and allow flexibility for team members to undertake other sub-tasks of the project without compromising results.

Aerial Images are required every few years in the City of Calgary to ensure that they are always up to date, which is beneficial for city planning and land use classification. OGL has previous experience performing airborne photogrammetry for the City of Calgary, and presumably the foreseeable future. Having updated DEMs will ensure that flood risk management will always be up to date with 100-year weather forecasting trends.

7 Compliance Statements

7.1 Transport Canada Compliance

Aerial photography and LiDAR data collection will be performed in accordance with all general operating and flight rules enacted by Transport Canada & the City of Calgary.

7.2 Alberta Land Surveyors – Standard Practices

All ground surveying procedures will conform to the recommended best standards and practices as outlined within the Alberta Land Surveyors' Association Manual of Standard Practice (ALS MSP). Since no changes to any existing registered plans are proposed, nor will any new plans be submitted for registration, there are no specific requirements for the precision of the GNSS surveyed points beyond what is required to perform the project.