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.

# Table of Contents

# List of Figures

# List of Tables

# 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.

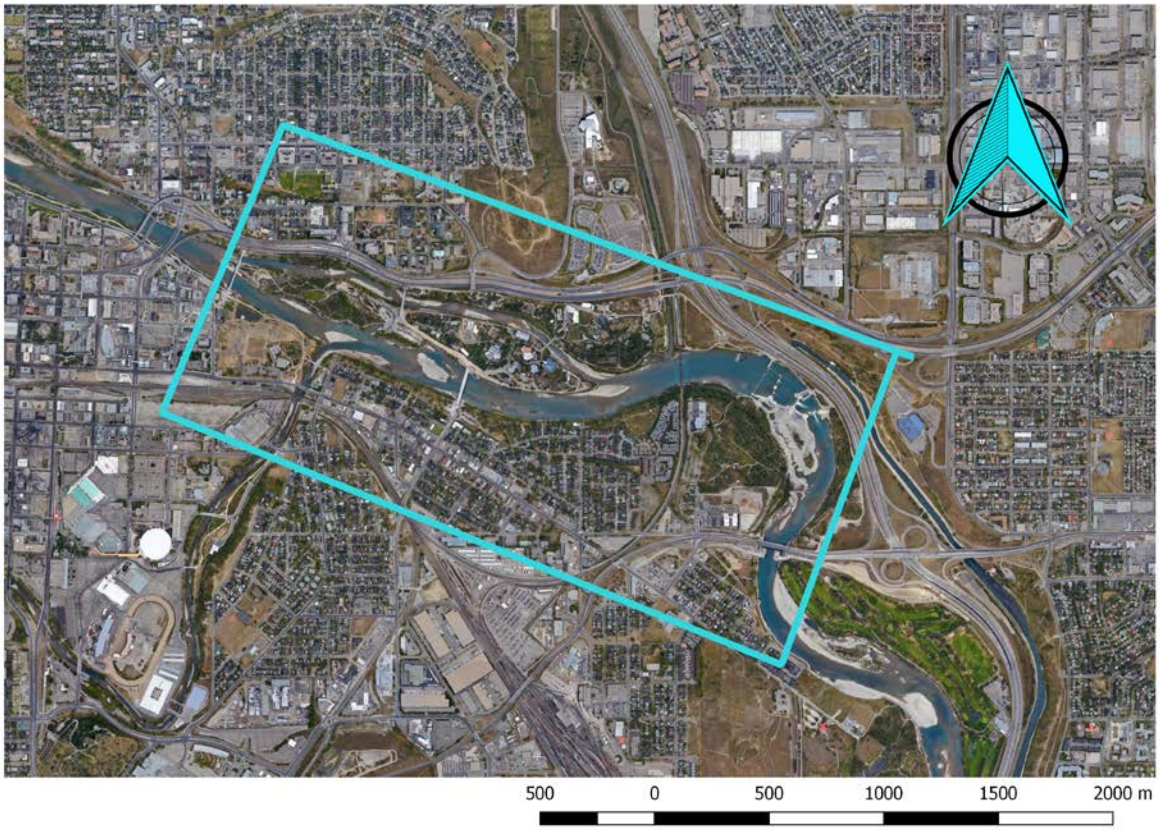



*Figure 1: Area of Interest (AOI)*

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 fields 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, 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 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 us 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 GNSS/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 photogrammetric 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, map, and 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 and Ranging Techniques' 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. These can be kept for reference and to provide to clients if feasible.

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.

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 lower elevations 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 damages, 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 appropriate flying height required to achieve the necessary ground sample distance (5cm/pixel). Number of flight lines will be calculated to ensure proper overlapping of adjacent images. Afterwards, a ground control survey will be performed on identifiable ground control points (GCPs) and check points that have been 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/aesthetic map of the Calgary Zoo will be created along with an orthorectified mosaic 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 goals 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 | GSD of 5cm |
| **2** | Ground Control Survey | 3D coordinates of check and control points to be used in calibration procedure | - Develop surveying skills using RTK<br>- Follow best standards and practices to ensure minimal errors in data | - Accuracy of the surveyed 3D coordinates<br>- Distribution of the selected points<br>- Geometry of network |
| **3** | Use automatic software for Camera Calibration – Bundle Adjustment | EOPS, IOPS, camera and intrinsic parameters from bundle adjustment | Apply theory from photogrammetry to calibrate camera and reduce errors in the measured image locations of check and control points | Accuracy of the camera calibration results |
| **4** | Classify and process LiDAR data | - Generate bare Earth point cloud<br>- 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<br>- Develop proper standards and practices related to map design and geospatial information | - Consistency with existing maps in terms of main features and reference frame<br>- Cartographic design and communication<br>- 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.<br>- Develop technical report writing skills<br>- 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 objectives 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** | - Full ground coverage and minimum economic cost<br>- Meet the GSD 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** | - Assess type, location and frequency of the selected points in the aerial images<br>- Compare measurements to a minimum of 3 ASCM coordinates<br>- 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: Peformance 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** | - Identify ground features using the LiDAR data and compare classified ground features with the images<br>- 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** | - Analyze the accuracy of the interpolation method and sampling type for the generation of DSM and DEM<br>- 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 mosiac |
| **Method used to measure** | - Scale of the orthophoto is uniform<br>- Distortion and relief displacement are minimized |
| **Responsibility: who measures/analyses/reports** | ZooOGL |
| **Frequency of measure** | Once |
| **Key targets** | Perform ortho-rectification for the aerial photos<br>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<br>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<br>- 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<br>- Define purpose, geospatial reality, accuracy of data, scale, users, conditions of use and technical limitations of the map<br>- 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<br>Present and report project processes<br>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 it will meet the precision, and accuracy proposed by the sponsor, as well as industry accepted best standards.

*Table 12: Specifications of different objectives in the project*

| Project Section | Specifications |
|---|---|
| **Flight Planning** | - 5 cm ground sample distance<br>- 60% forward overlap of adjacent images<br>- 30% overlap between adjacent flight lines<br>- 1 perpendicular flight line<br>- minimum required flight lines |
| **Ground Control Survey** | - Performed with Trimble R10s utilizing RTK with a single baseline<br>- 20 mm minimum horizontal precision @ 1σ<br>- 25 mm minimum vertical precision @ 1σ |
| **Mapped Features** | - Shapefile format |
| **Orthomosaic Photo** | - GeoTIFF format |
| **Bare Earth point cloud** | .las format |
| **Digital Elevation Model** | - Regularly gridded at 0.5m<br>- 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, 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 with a minimal number of flight lines is designed to be parallel to the Bow River. This is indicated by the green markers in Figure 2 which also indicates the flight trajectory over 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 GSD 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 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 are defined. Some additional images at the periphery outside the AOI will also be captured to ensure full coverage of the AOI.

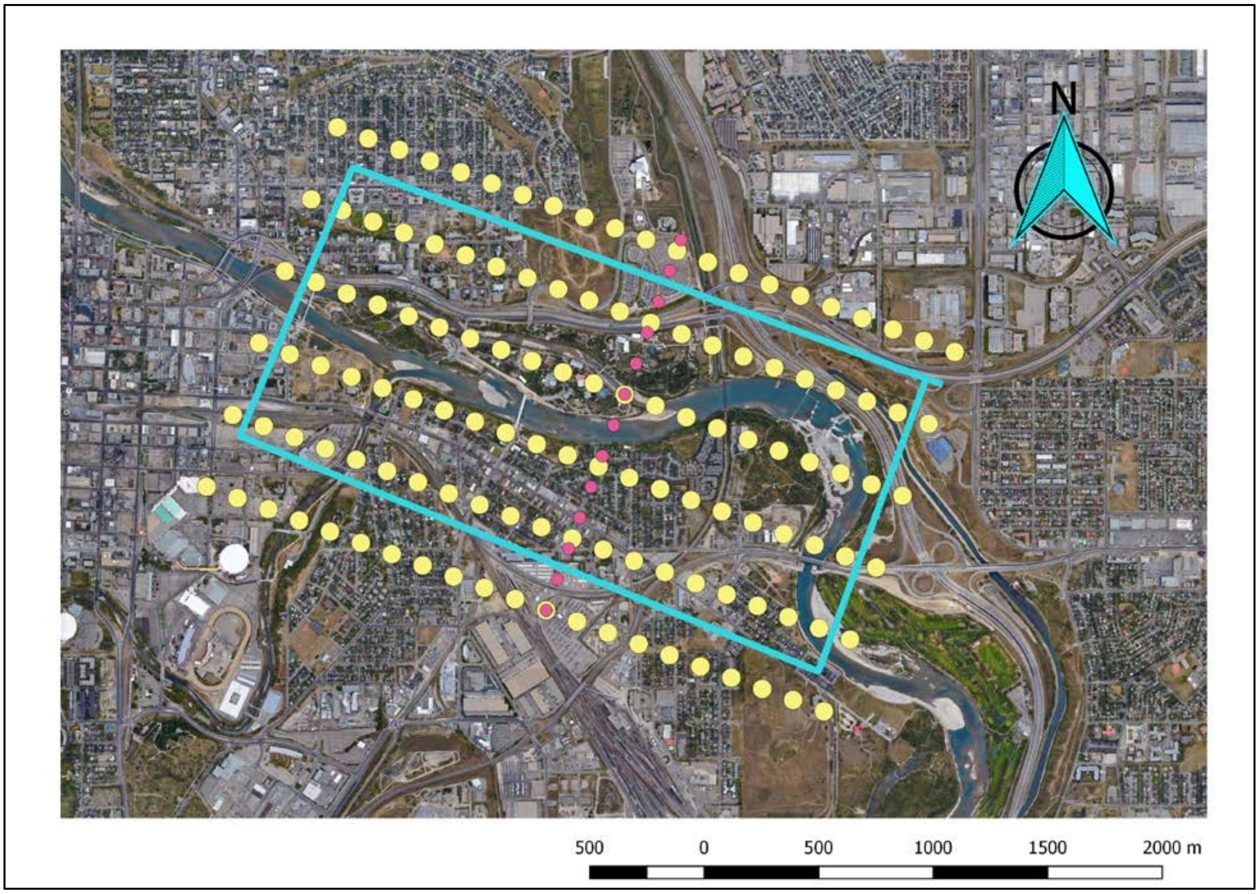



*Figure 2. Flight lines and location of image capture points for the chosen AOI*

## 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 an 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 inputs, 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 will be merged into one orthomosaic photo that can be used to measure true distances, angles and areas with minimized 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.

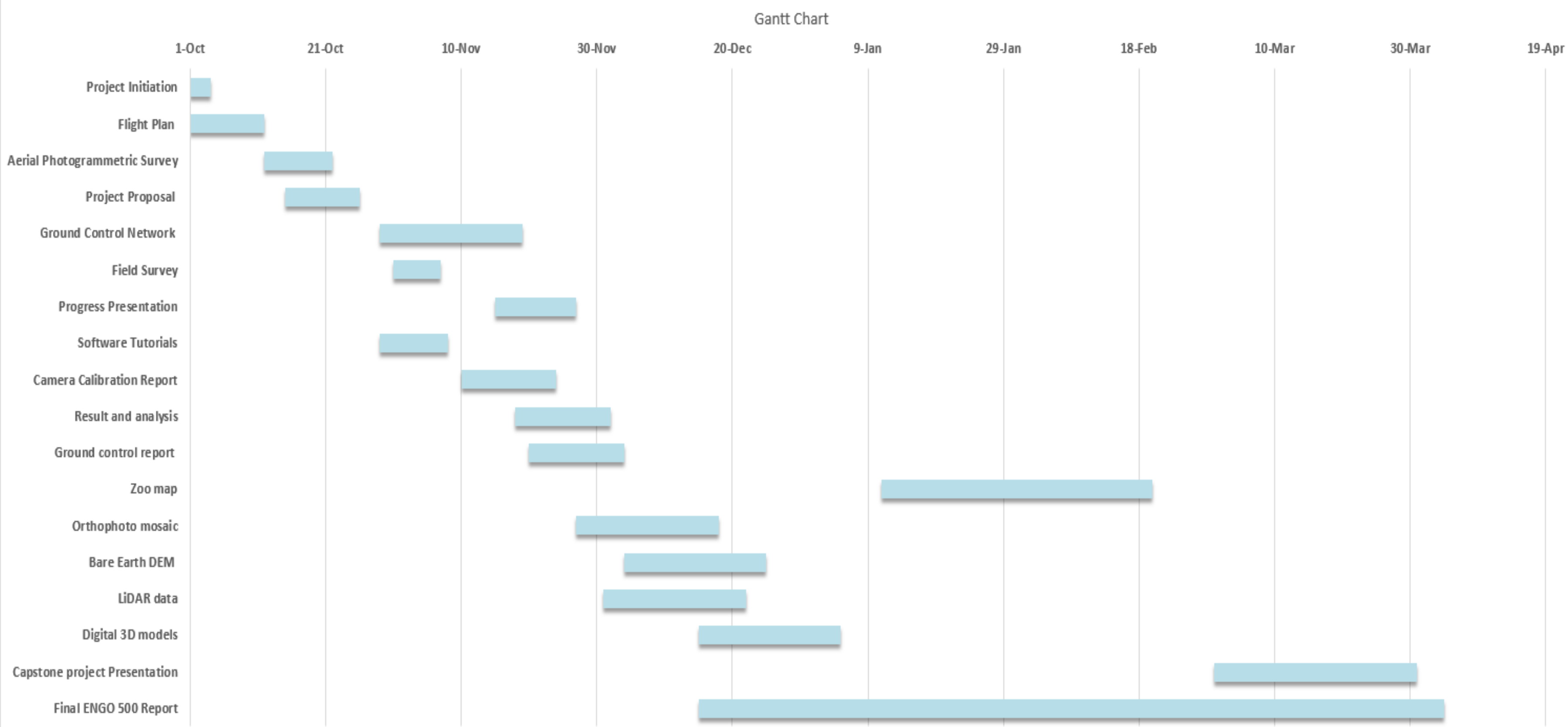
One way to build a team is to develop and improve the interpersonal relationships between the members and to quickly resolve any possible conflicts. If there was a discontent member or if there were members in conflict, it may slow down or even halt the progress of the project, therefore it is important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




| | Final ENGO 500 Report | Capstone project Presentation | Digital 3D models | LiDAR data | Bare Earth DEM | Orthophoto mosaic | Zoo map | Ground control report | Result and analysis | Camera Calibration Report | Software Tutorials | Progress Presentation | Field Survey | Ground Control Network | Project Proposal | Aerial Photogrammetric Survey | Flight Plan | Project Initiation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start Date | 15-Dec | 1-Mar | 15-Dec | 1-Dec | 4-Dec | 27-Nov | 11-Jan | 20-Nov | 18-Nov | 10-Nov | 29-Oct | 15-Nov | 31-Oct | 29-Oct | 15-Oct | 12-Oct | 1-Oct | 1-Oct |
| Duration (days) | 110 | 30 | 21 | 21 | 21 | 21 | 40 | 14 | 14 | 14 | 10 | 12 | 7 | 21 | 11 | 10 | 11 | 3 |

*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:<br> - KML file with camera locations<br>- 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:<br>- Aerial images<br>- unclassified LiDAR data<br>- Tragectory 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:<br>- Ground control network design with (control points, check points - monuments)<br><br>from ZooOGL to ENGO 500 Coordinator:<br>- 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:<br>- images of the ground points surveyed<br>- 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:<br>- have an idea on how to use the software (Trimble UASMaster) for analysising 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:<br>- Camera calibration report with the updated IOPs and recommendat ions | | 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:<br>- Report on the triangulated photo exterior | | 1/25/2019 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | orientation parameters, results, and analysis<br>- 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:<br>- 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:<br>- 2D/3D map with the indentified features<br><br>- shapefie 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:<br>- Ortho-rectified images<br>- Ortho-rectified images of AOI<br>- 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:<br>- Bare Earth point cloud<br>- .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:<br>- Bare Earth DEM regularly gridded at 50 | | 3/22/2019 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | c - GeoTIFF format<br><br>- Full feature DSM regularly gridded at 50 cm<br>- 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<br>- 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.