# HAZARD IDENTIFICATION AND EVALUATION USING UAV PHOTOGRAMMETRY FOR PIPELINE ROUTING

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Challenges from North to South
Des défis du Nord au Sud

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ABSTRACT
The geotechnical engineering aspect of pipeline route selection is a multifaceted process involving detailed studies of ground conditions, natural hazards, and geological history. Assessing ground conditions typically involves preliminary desktop based terrain evaluation tools, boots on the ground field investigations, drilling/sampling/testing, and remote sensing data collection and interpretation. Recent advancements in the field of Structure from Motion (SfM) 3-dimensional (3D) photogrammetry eliminate the onerous requirements of ground control and enable the generation of high resolution digital terrain models at variable resolutions. Photographs can be taken from a variety of aerial platforms or terrestrial locations. In this project we demonstrate the use of Oblique Aerial Photogrammetry from a UAV (OAP-U) for the generation of a detailed terrain models for the evaluation of a pipeline route crossing a deep valley 200 km from Vancouver, British Columbia. The resultant data was used to map slope angles, geological structure, rockmass conditions, thereby allowing for the optimisation of the pipeline route, and to establish a baseline 3D model of the site that could be used for future comparisons to assess ground changes. The incorporation of OAP-U techniques into field mapping projects has greatly increased the information obtained in the field and resulted in a greater understanding of the terrain.

RÉSUMÉ
La contribution géotechnique à la sélection des tracés de pipeline est un processus multidimensionnel qui intègre les études détaillées des conditions de terrain, les aléas naturels et l'histoire géologique de la région. L'évaluation des conditions de terrain inclue généralement des outils d'évaluation préliminaire de bureau, une visite du site, le forage, l'échantillonnage (incluant tests de laboratoire), la collecte de données de télédétection et l'interprétation de ces données. Des avancements récents dans le domaine de la photogrammétrie avec la méthode «Structure from Motion (SfM) éliminent les exigences onéreuses de cibles de control et permet la génération de modèles numériques de terrain à haute résolution avec des résolutions variables. Les photographes peuvent être acquises d'une variété de plateformes aériennes ou terrestres. Dans ce projet, nous démontrons l'utilisation de la photogrammétrie aérienne oblique (PAO) d'un véhicule aérien sans pilote (PAO-U) pour la génération de modèles de terrain détaillées pour l'évaluation d'un itinéraire de pipeline traversant une vallée profonde, situé à 200 km de Vancouver, en Colombie-Britannique. Les données qui en résultent furent utilisées pour cartographier les angles de pente, les structures géologiques, et les conditions de masses rocheuses, permettant ainsi l'optimisation du tracé de pipeline et pour établir un modèle 3D de base du site qui pourrait servir à évaluer les changements futures du terrain. L'incorporation de techniques de PAO-U dans les projets de cartographie sur le terrain a considérablement augmenté les renseignements obtenus sur le terrain et a donné lieu à une meilleure compréhension du terrain.

## 1 INTRODUCTION

The geotechnical engineering aspect of pipeline route selection is a multifaceted process involving detailed studies of surface and sub-surface ground conditions, natural hazards, and geological history. Assessing ground conditions typically involves a preliminary desktop based terrain evaluation, boots on the ground field investigations, drilling / sampling / testing, and remote sensing data collection and interpretation. Various pipeline projects currently under consideration in Canada will traverse rugged terrain in western Alberta and British Columbia. Field work consisting of outcrop mapping and rockmass evaluation is typically constrained by visual examination at ground level, broad scale analysis conducted from a helicopter and regional scale analysis conducted from airborne LiDAR data and high resolution air photos.

Recent advancements in the field of Structure from Motion (SfM) 3-dimensional (3D) photogrammetry eliminate the onerous requirements of ground control and enable the generation of high resolution digital terrain models at variable resolutions. The SfM approach to photogrammetry requires a large number of significantly overlapping photos to reconstruct a 3D surface. Photographs can be taken from a variety of aerial platforms or terrestrial locations (Gauthier et al., 2015). Aerial based approaches, commonly referred to as Oblique Aerial Photogrammetry (OAP), are typically collected using a helicopter, unmanned aerial vehicle (UAV), or small fixed wing aircraft (Lato et al., 2015). In this project we demonstrate the use of OAP from a UAV (OAP-U) for the generation of a detailed terrain model for the evaluation of a pipeline route crossing through a deeply incised valley near Hope, British Columbia. The OAP-U data were collected on site by engineers conducting the field evaluation in approximately 60 minutes of flight time. The resultant data was used to map slope angles, geological structure, rockmass conditions, thereby allowing for the optimisation of the pipeline route, and to establish a baseline 3D model of the site that could be used for future comparisons to assess ground changes. The data collected required a two person team with knowledge of UAV operation and photogrammetry principles.

The use of OAP-U provided a rich 3D data source which facilitated an understanding of the site not possible with traditional approaches. The incorporation of OAP-U techniques into field mapping projects has greatly increased the information obtained in the field and resulted in a greater understanding of the terrain.

### 1.1 OAP-U applications in the geosciences

The use of UAV based technology in the field of geotechnical engineering has rapidly expanded in the past five years due to the affordability of the technology and the computational programs amenable to the data UAVs collect. One of the most notable developments is through the robust SfM photogrammetry algorithm, explained in detail by Snavely et al. (2008), Westoby et al. (2012), and Gauthier et al. (2015), which facilitates the generation of 3D models from the still imagery collected by UAVs without the need for ground control.

The engineering applications of 3D data generated by UAVs is evolving rapidly. Notable applications of UAV in recent literature include the automated mapping of landslide fissures from still imagery collected by UAV (Stumph et al., 2013, Walter et al., 2014), developing digital elevation models from overlapping UAV still imagery (Rock et al., 2011), temporal soil erosion monitoring (d'Oleire-Oltmanns et al., 2013) and structural mapping of exposed rockmasses (Vasuki et al., 2013). A thorough review of mapping applications of UAV based technologies has been published by Nex, and Remondino (2014).

## 2 UAV technology

UAV technologies have greatly improved in the past five years facilitating the development of practical engineering applications. Significant improvements have been made with respect to flight control/duration, onboard camera technology, and operationally through live HD video streaming technology. The UAV used in this project is a DJI Inspire 1 Quadcopter (Figure 1). The UAV is equipped with a 4k video camera capable of simultaneously capturing 12-megapixel still images. The camera has an effective focal length of 20 mm ($94^{o}$ field of view) and a fixed aperture of f/2.8.

The camera is integrated to the UAV body through a stabilised 3-axis gimbal that is remotely controlled by the pilot (or co-pilot) at ground level. The gimbal utilizes advanced servo mechanisms allowing for seamless rotation of the camera while the UAV is in flight. The camera offers manual settings with respect to ISO, shutter speed, and white balance allowing greater control over images to be used for photogrammetry. The live HD video stream allows the pilot to ensure proper settings during data collection and accurately assess the required overlap between individual photos during data collection.

The Inspire 1 UAV is equipped with a motorized landing gear that retracts once the UAV is in flight. When the landing gear is retracted the camera has an unobstructed $360^{o}$ horizontal view. This expanded field of view allows photographs to be captured along vertical rock faces while the UAV remains on a level flight plan.

During operation, the Inspire 1 is GPS connected, which has two significant benefits for photogrammetry data collection:

- Each photo captured by the Inspire 1 is geotagged with latitude and longitude coordinates
- During windy flight operations the Inspire 1 will self-stabilize when hovering to allow the pilot to take photographs

The geolocation features in combination with the image capture / streaming technology render the Inspire 1 UAV a suitable instrument for photogrammetry data collection.

Figure 1. Photograph of the DJI Inspire 1 UAV prepared for take-off. Note the camera attached by a 3-axis gimbal on the front of the UAV.

### 2.1 OAP-U photogrammetry data collection

Collecting Oblique Aerial Photogrammetry data from a UAV (OAP-U) requires a systematic approach of a large number of overlapping images distributed evenly across the target (slope face). Typically during OAP-U data collection the UAV will be flown parallel to the rock face at a set elevation above ground level while the camera operator captures images at regular intervals. The ability of a UAV to hover over a given location increases the reliability of this process as photographs can be captured at calculated intervals. This results in photogrammetry models with less noise and faster processing times. The intricacies of OAP data collection and 3D model generation are presented in detail by Gauthier et al. (2015).

## 3 Dry Gulch

The Trans Mountain pipeline Expansion Project (TMEP) is proposing a 994 km expansion of the existing Trans

Mountain pipeline between Edmonton, AB and Burnaby, BC. The project is currently before the National Energy Board for review. Part of the ongoing work presently conducted by BGC for the project is a geotechnical evaluation of the proposed pipeline route with respect to ground conditions, geohazards, constructability and operation. Various remote sensing tools are used in conjunction with traditional field mapping to develop a full geotechnical understanding and assessment of risks.

The OAP-U pilot project was conducted approximately 200 km east of Vancouver, BC (Figure 2) where the proposed crossing of the TMEP pipeline transects a deeply incised glacial outwash 'v-shaped' valley, named Dry Gulch. The valley is approximately 200 m across from crest to crest and approximately 90 m deep.

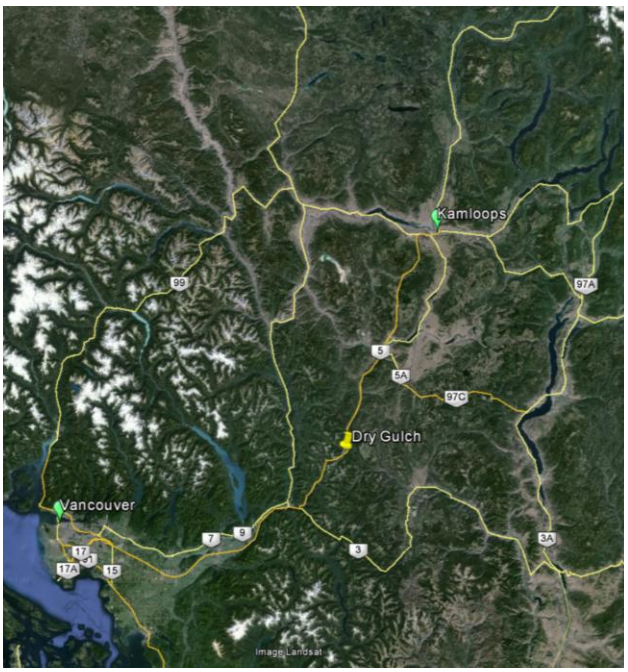


Figure 2. Location map of the Dry Gulch valley in relation to Kamloops, BC and Vancouver, BC (base imagery from www.maps.google.com)

## 3.1 Data collection at Dry Gulch

The UAV data collection at Dry Gulch involved a two person team to conduct the photogrammetry survey. The flight of the Inspire 1 UAV was controlled by one operator and the positioning of the camera and acquisition of video and still imagery was controlled by a second operator (Figure 3). Due to the limited battery life of approximately 15 minutes of inflight operation, plus five minutes reserved for safe landing, three separate flight plans were executed as follows:

- Detailed still image collection of the north side of the valley for generation of a photogrammetry model
- Detailed still image collection of the south side of the valley for generation of a photogrammetry model
- High altitude video and still image collection for generation of overall valley topography model.

During flight operation and data collection the UAV must remain within line of sight of the operator and within a distance of 1.5 km. The UAV is also restricted to a 90 m vertical separation from the operator and cannot be operated within 150 m of a freeway. These operational restrictions require pre-flight planning to ensure the required data can be collected from the pilot's position.

Figure 3. UAV pilot (left) and co-pilot (right) controlling the Inspire 1 drone at Dry Gulch

Approximately 200 still photographs were collected along each side of the valley at Dry Gulch. The photographs were collected along horizontal flight lines at the same elevation. The north valley wall was captured in three passes, as illustrated in Figure 4. The UAV hovered during image capture to limit the blur in the images. In addition to the horizontal passes individual photos were captured at specific locations where greater resolution was required. The UAV during flight is illustrated in Figure 5.

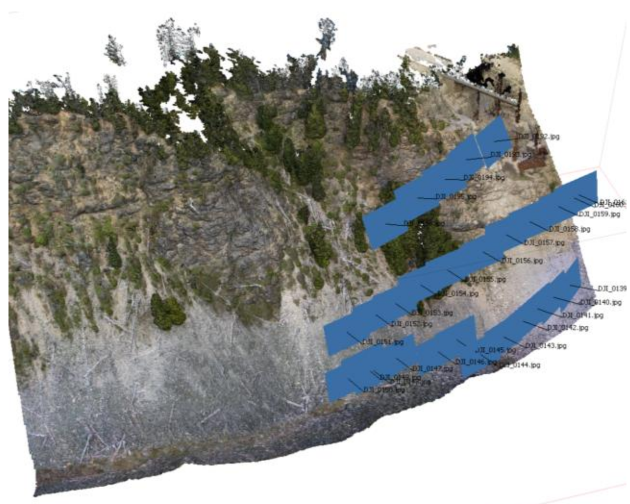

Figure 4. Locations of the individual camera locations used to generate the 3D photogrammetry models for the north side of the Dry Gulch valley (each blue square represents a single photograph location).

Figure 5. The DJI Inspire 1 UAV taking off at Dry Gulch. The north side valley wall is visible in the background of the photograph.

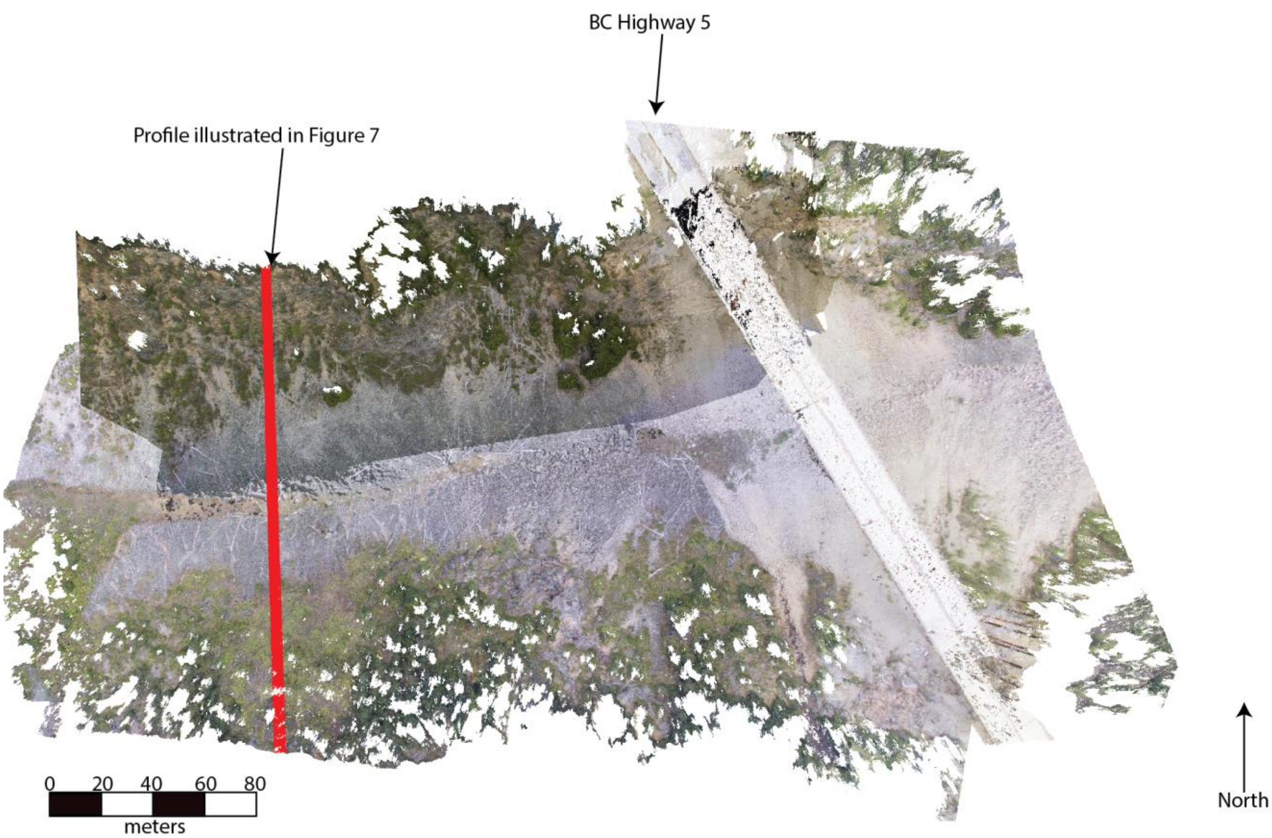


Figure 6. Plan view visualization of the OAP-U data collected at the Dry Gulch TMEP proposed pipeline crossing.

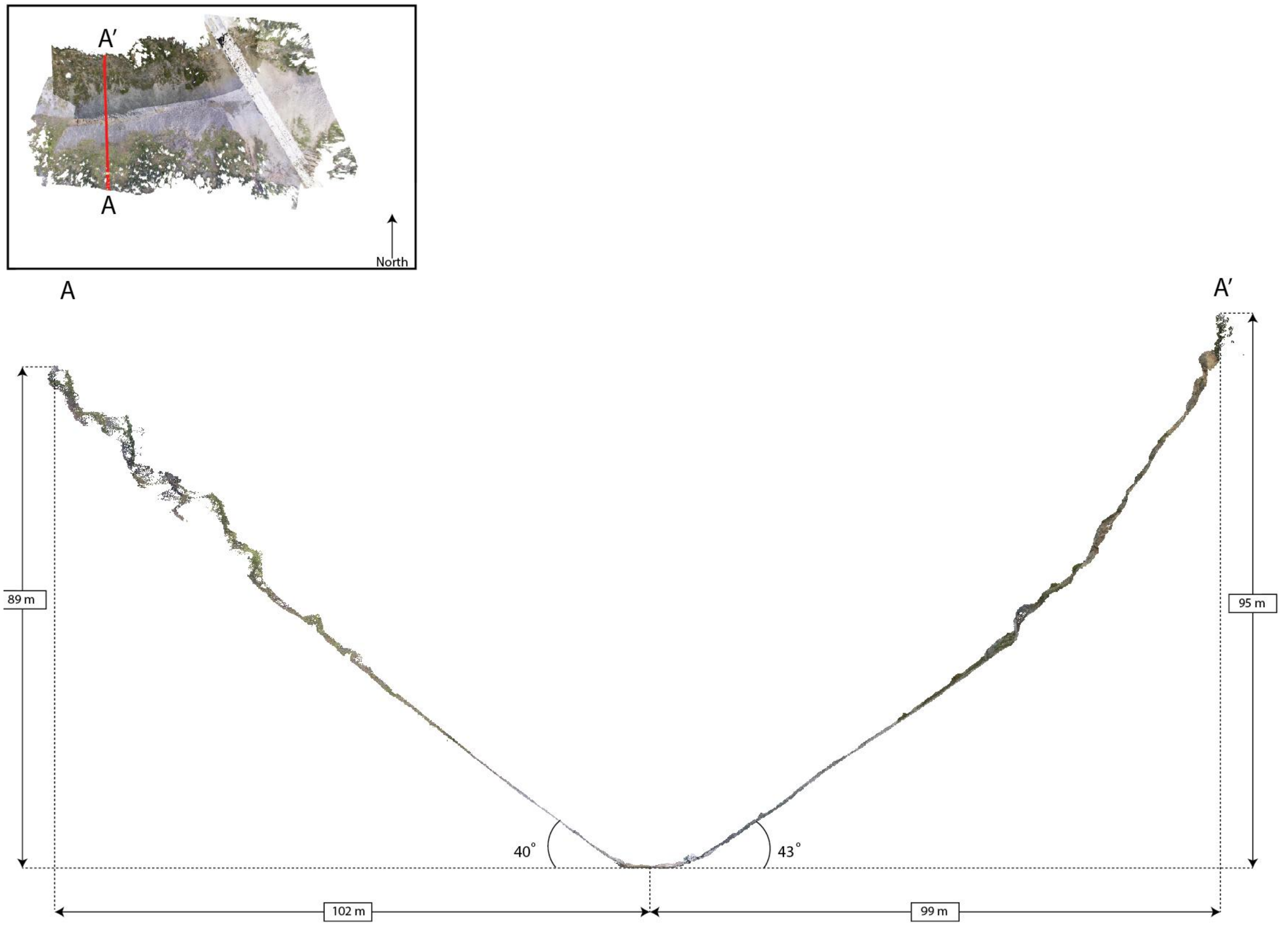


Figure 7. Annotated profile generated from the 3D photogrammetry data collected at Dry Gulch, BC. The look direction of profile is: N280°.

The still photographs collected at Dry Gulch were processed using Photoscan (Agisoft, 2015) to develop a 3D point cloud model of the imaged region, a plan view of the 3D point cloud is illustrated in Figure 6.

### 3.2 Application of UAV data (results)

The 3D point cloud models of the Dry Gulch valley were used in the pipeline route planning phase of work. Specifically, the OAP-U data were used to:

- Identify outcropping rock and measure its spatial extent and coverage
- Measure the spatial characteristics of the valley, including (Figure 7):
    - Valley width
    - North and south side valley height
    - Angle of valley walls in sections of rock and sections of talus
- Measure orientation and persistence of large structural features
- Measure orientation of valley walls
- Identify alternate pipeline paths
- Identify rockmass scars and rockslide debris on the valley floor

The assessment of the above mentioned properties in a systematic and accurate fashion facilitated a discussion on the optimal route selection with respect to constructability of the pipeline, safety during construction, and minimal risk to the pipeline during operation.

## 4 CONCLUSIONS

The use of UAV technology during the planning phase of pipeline routing proved to be a valuable tool for sites that pose significant challenges or hazards to assess and map using traditional approaches. The work conducted at Dry Gulch was a pilot project with unknown engineering or decision making applications. The high quality of the 3D data and the 4k video collected by the UAV have spurred a wide array of applications within the pipeline projects at BGC and various other geohazard assessment projects. Future development work will include analytical comparisons between high accuracy terrestrial lidar data and OAH-U data. This will facilitate a better understanding of the data limitations.

## 5 ACKNOWLEDGEMENT

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## 6 REFERENCES

Agisoft. 2015. Photoscan Professional. St. Petersburg, Russia.

d'Oleire-Oltmanns, S., Marzolff, I., Peter, K. D., & Ries, J. B. (2012). Unmanned Aerial Vehicle (UAV) for monitoring soil erosion in Morocco. Remote Sensing, 4(11), 3390-3416.

Gauthier, D., Hutchinson D.J., Lato M., Edwards T., Bunce C., Wood D. (2015) "On the precision, accuracy, and utility of oblique aerial 'structure from motion' photogrammetry for rock slope monitoring and assessment" Canadian Geotechnical Conference, Quebec City.

Lato, M. J., Gauthier, D., & Hutchinson, D. J. (2015). Selecting the Optimal 3D Remote Sensing Technology for the Mapping, Monitoring and Management of Steep Rock Slopes Along Transportation Corridors. In Transportation Research Board 94th Annual Meeting (No. 15-3055).

Nex, F., & Remondino, F. (2014). UAV for 3D mapping applications: a review. Applied Geomatics, 6(1), 1-15.

Rock, G., Ries, J. B., & Udelhoven, T. (2011). Sensitivity Analysis of UAV-Photogrammetry for Creating Digital Elevation Models (DEM). In Proceedings of Conference on Unmanned Aerial Vehicle in Geomatics.

Snavely, N., Seitz, S. M., & Szeliski, R. (2008). Modeling the world from internet photo collections. International Journal of Computer Vision, 80(2), 189-210.

Stumpf, A., Niethhammer, U., Rothmund, S., Mathieu, A., Malet, J. P., Kerle, N., & Joswig, M. (2013). Advanced image analysis for automated mapping of landslide surface fissures. In Landslide Science and Practice (pp. 357-363). Springer Berlin Heidelberg.

Vasuki, Y., Holden, E. J., Kovesi, P., & Micklethwaite, S. (2013). A geological structure mapping tool using photogrammetric data. ASEG Extended Abstracts, (1), 1-4.

Walter, M., Niethammer, U., Rothmund, S., & Joswig, M. (2009). Joint analysis of the Super-Sauze (French Alps) mudslide by nanoseismic monitoring and UAV-based remote sensing. First Break, 27(8).

Westoby, M. J., Brasington, J., Glasser, N. F., Hambrey, M. J., & Reynolds, J. M. (2012). 'Structure-from-Motion' photogrammetry: A low-cost, effective tool for geoscience applications. Geomorphology, 179, 300-314.