Error Propagation in Structure from Motion and the Effect on Multi-Temporal Change Detection

**Economy**

**Technology**

**SfM**

SfM-MVS is a computer vision technique built on photogrammetric theory whereby the 3D geometry of a scene is reconstructed using redundant 2D imagery. When a scene is viewed from different perspectives, the relative change in position of 3D objects is directly constrained by the change in position of the imaging sensor. By identifying features known as keypoints, then matching these features across images, we can create a set of tielines whose lengths change covariantly with the changes in camera position, and are a function of the 3D structure of the scene being imaged.

The creation of a spatially accurate dense point cloud representation of a physical scene can be broken into 9 steps.

1. Extract features in the images
2. Pairwise matching to calculate the fundamental matrix
3. Select and verify the initial pair of images
4. Triangulation of 3D points from initial pair
5. Bundle Adjustment to reduce error of 3D points
6. Add image initial pair, triangulate and store new points to the model
7. Repeat Bundle Adjustment every few images
8. Repeat steps 6 and 7 until entire block has been reconstructed

The result at this point is a sparse point cloud and highly constrained camera positions including x,y,z, and pitch, roll, and yaw information.

The MVS step (step 9) follows this process and uses the highly-constrained camera locations and orientations to increase the density of the point cloud by reconstructing the features between the points generated during SfM reconstruction. This is usually accomplished by using several processes (algorithms) that leverage depth maps, convex hulls, and silhouette extraction to densify the sparse point cloud that resulted from the SfM.

The result is a colorized point cloud with a density that can exceed those produced by terrestrial laser scanners. SfM-MVS can generate point densities above 10,000 points per square meter given the requisite input imagery resolution and processing parameters.

SfM-MVS has an advantage over traditional methods such as traditional photogrammetry, traditional topographic surveys, differential GPS surveys, LiDAR scanning, laser scanning, and total station surveys, in both cost and ease of data collection. Additionally, SfM-MVS might provide a better dataset as well.

**SfM in the Geosciences**

SfM-MVS is a new paradigm in the geosciences and represents a significant advancement in photogrammetry, surveying, and spatial modeling capabilities

Traditional photogrammetry is developing into a digital parallel that is less restricted by imaging requirements. The results of this digital revolution are high quality, spatially dense, colorized 3D point clouds.

Geomorphological processes including erosion, chemical and physical weathering, ecological condition and influence, and natural disasters shape the surface of the Earth. Modeling these phenomena in 3D provides a valuable opportunity for understanding environmental processes

Financial and methodological constraints on traditional techniques for collecting spatial data -- such as photogrammetry, traditional topographic surveys, differential GPS surveys, LiDAR scanning, laser scanning, and total station surveys -- prevent wide scale collection of new 3D datasets

SfM-MVS has an advantage over these traditional methods in both cost and ease of data collection

Physical environmental conditions as well as the physical nature of the subject matter will affect the accuracy of the SfM-MVS products. Some well documented challenges in the SfM-MVS workflow involve texture and color contrast of the subject matter, lighting conditions, orientation of the image set, and the camera used to collect the imagery

Because the SfM work-flow looks for feature correspondence between images, if the features move relative to each other between sequential image captures, the least squares regression cannot resolve the position of the keypoint that has been identified across the images. This problem is encountered frequently when the images contain tree canopies or water bodies. A slight breeze can cause tree canopies to move enough such that the tops of trees fall completely out of the model. Running water or movement on the surface of water bodies also causes holes in the point cloud

**Change Detection**

SfM uses MLE, ANN, and RASNAC which will generate slightly different results every time a dataset is processed

Internal error propagation is the focus.

**Methods**

Using a DSM comprises too many steps (All of SfM and MVS) that are potentially introducing error into the final information product (DSM)

flattening point cloud to DSM is not future proof – point clouds are the future

not to mention multiple values in a single raster grid are common

Narrow focus into first step (Just SfM)

focus on camera positions that result from SfM (the Motion part of SfM)

Ability to quantify reliability of camera positions from SfM and IMU could effect efforts of improving timeliness down the road

**Code Book**

**UNM Dataset FAMIS**

* Eagle Ranch SSCAFCA Bridge
  + size (Gb):
  + Number of Input Photos
  + type: raster
  + Location:
  + GSD:
  + Sensor:
  + CRS:
  + input image number:
  + RMSE\_xy
  + RMSE\_z

**CUAS Dataset C-Astral**

Austria Dataset C-Astral

* Austria UAS Test Site
  + size (Gb):
  + Number of Input Photos
  + type: raster
  + Location:
  + GSD:
  + Sensor:
  + CRS:
  + input image number:
  + RMSE\_xy
  + RMSE\_z

**Processing Workflow Outline**

Full Script in Appendix I

1. Start new project and save as specific unique project name
2. Load photos
3. Make 30 chunks with the same photos in each
4. Match and align all chunks (SfM)
5. Export Camera Positions for each of the 30 Chunks (Manual)

**Analysis Workflow Outline**

**Executed for UNM and CUAS data**

* Combine all 30 csv files into single database
* Camera ID is image file name
* 30 locations with same Camera ID name –use loop number ID for true unique ID (UID)

for all camera positions representing same image:

* Mean
* Variance
* Standard Deviation

Evaluate normality with Pearson chi-squared test or Shapiro-Wilks test, also need to look at central limit theorem – discuss implications

Determine the maximum error that can occur as a result of SfM – discuss implications for change detection