Using Non-linear Least Squares for Minimizing the Reprojection Error in Image Stitching

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Overview

Background and Motivation

The Gantry and Large Scale Mosaicking

World's Largest High-throughput Phenotyping Machine

The video

The Gantry and Large Scale Mosaicking

- Phenotype: the set of observable characteristics of an individual resulting from the interaction of its genotype with the environment.
- Genotype: the genetic constitution of an individual organism.
- The Goal of the Project is to find genes that makes individual plants to have a specific characteristics, i.e. Drought Resistant.

The Gantry and Large Scale Mosaicking

The Gantry:

- 2 Acres of land
- Half a dozen sensors
  - RGB cameras (0.3 mm per pixel)
  - PS II for Photosynthesis
  - FLIR / Thermal Camera
  - Hyper Spectral Camera
  - 3D Laser Scanner

The Gantry and Large Scale Mosaicking

- Gantry moves N to S and E to W
- Heavy metals and magnetic fields on the machine
- Relative Coordinate System: Barcodes on rails
- Conversion to GPS is noisy
- Wind causes displacement of the camera box

Resulting GPS is not enough for stitching images.

- Estimate pairwise transformations (translation is enough in many cases)
- Correct GPS coordinates (geo-correction)

Drone Images: The More General Case

- Drone is used more often
- More general and distinct features
- Challenge: transformation is not only **translation**.
  - Rotation
  - Scale
  - Tilting

Consistency: Important in Large Scale Mosaicking

- Pairwise image stitching has beaten to death
- Multi image stitching is more interesting
- Challenges
  - Minor error can propagate throughout the mosaic
  - Drift and inconsistency
- Old approach for multi image stitching in the literature
  - Iterative stitching: drift can cause huge inconsistency

Speed and Performance: Another Challenge in Large Scale Mosaicking

- Better approach
  - Optimize pairwise transformations to minimize a score (projection error)
  - Non linear and slow procedure

My Goal: Linear Method for Minimizing the Drift Error

- My goals
  - Control the drift
  - Speed up the process
- Proposed method works perfectly for the gantry
- Make it a general method for other applications
- This presentation
  - Discuss one of the methods in the literature
  - Illustrate the challenges of the mostly used approach

Image Stitching Short Review

Pairwise Transformations between Pairs of Images

Four famous geometric transformations:

- Translation
- Similarity
- Affine
- Homography

Pairwise Transformations between Pairs of Images

Translation

Pairwise Transformations between Pairs of Images

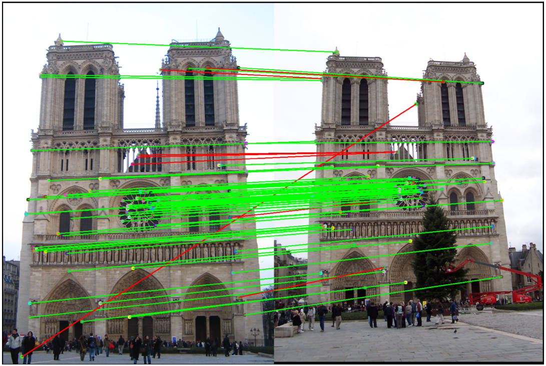
Similarity

Affine and Homography

Estimating Pairwise Transformation using SIFT Key point Matching

- Stitch two images
  - Find important visual keypoints in each image (SIFT/SURF)
  - Match the keypoints based on their descriptor (KNN)
  - Estimate the desired transformation (RANSAC)

Estimating Pairwise Transformation using SIFT Key point Matching

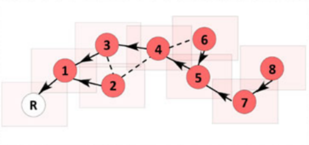


MGRAPH Method for Large Scale Image Stitching

Creating a GRAPH of Image Adjacency

- Works on Drone images (swarm of drones)
- Estimate pairwise transformation for each image and its neighbor
- Form a Graph that represents the adjacencies between images (build it on the go)
- Merge and split the graph as needed (weak and strong edges)
- Extract a minimum spanning tree from this graph
- Calculate absolute homographies w.r.t the root (reference)
- Minimize the reprojection error
- Use absolute homographies to warp and stitch the images

Reference Points and Absolute Homographies



- Matches between image i and j

$$M_{ij} =< p_i, p_j >$$

- Pairwise Homography (similarity in their case)

$$p_i \approx H^{ij} p_j$$

- Absolute Homographies

$$H^{iR} = H^{ij} H^{jR}$$

Takes a point from coordinate system of R to the coordinate system of i

Reprojection Error using Absolute Homographies

- Projection error

$$r = p_i - H^{ij} p_j$$

- Using the underlying graph, the absolute homographies and SIFT matching form the following optimization function (reprojection error)

$$\sum_i \sum_j \sum_{p \in M_{ij}} d(p_i, H^{iR} (H^{jR})^{-1} p_j)$$

Non-linear Least Squares Optimization

- Minimize the reprojection error for parameters of absolute homographies

$$\sum_{i} \sum_{j} \sum_{p \in M_{ij}} d(p_i, H^{iR}(H^{jR})^{-1} p_j)$$

- Because of the multiplication of the two H and the inverse this method is a Non-linear least squares (the function d).

Non-linear Least Squares Optimization

- Non-linear least squares:

$$\arg\min_{\theta} S = \sum_{i=1}^{m} r_i^2$$

$$r_i = y_i - f(x_i, \theta)$$

- In our case:
  - p_is and p_js are in accordance x_is and y_is.
  - H_{iR}s are in accordance to θ and f is $H^{iR}(H^{jR})^{-1}p_j$.
  - d is the squared of the residual or the euclidean distance.

Non-linear Least Squares Optimization

- Non-linear Least Squares

$$\arg\min_{\theta} S = \sum_{i=1}^{m} (y_i - f(x_i, \theta))^2$$

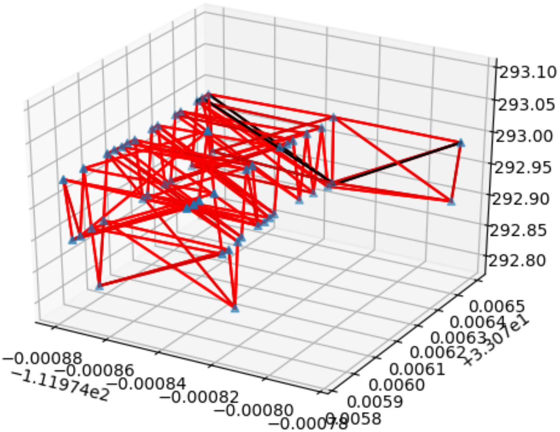
- Available methods to optimize
  - GaussNewton method
  - LevenbergMarquardt algorithm
  - QR decomposition
  - Singular Value Decomposition
  - Gradient Methods

Use Non-linear Least Squares to Minimize Reprojection Error

- Two libraries for Non-Linear Least Squares optimizer
  - Python Scipy Non-Linear Least Squares optimizer
    - Uses QR method
    - Form Jacobian and decompose it to QR.
    - Form system of equations and solve for parameters
  - C++ Ceres
    - Uses Levenberg-Marquardt algorithm
    - Remember LMA interpolates between the GaussNewton algorithm gradient descent method.
    - Calling a C++ function from python (wrapper for Ceres) not successful so far.
- Non-linear optimization is usually slow and inaccurate in some cases.

Results

Results



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292.85
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0.0065
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0.0062
0.0061
0.0060
0.0059
0.0058
+3.307e1
−0.00088
−0.00086
−0.00084
−0.00082
−0.00080
−0.00078
−1.11974e2

Results

Gantry Ortho

The End

Thank you Very much for you attention.

I will upload the slide to my homepage at http://vision.cs.arizona.edu/ariyanzarei/