Photo Reconstruction and Object Classification with OpenCV[1] and PointNet[2]

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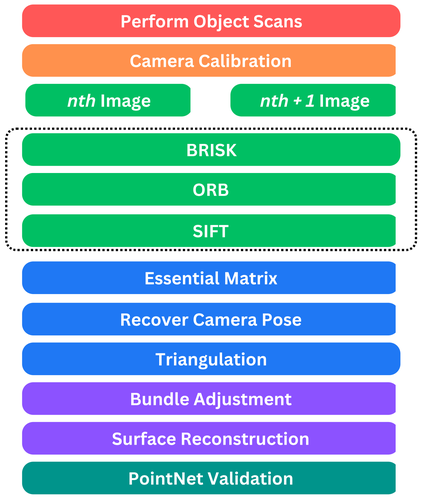
1 Background

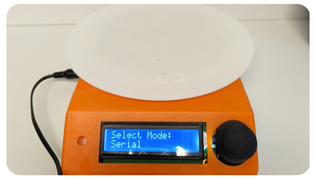
Images in their purest form can only provide information in a two-dimensional space, which lacks the information that can be found in the three-dimensional space of the real world. Information such as the cross-sectional shape of each part of an object and the volumetric properties of the object is lost, and these factors are often a method used to help classify complex objects, such as fossils and manufacturing defects. To leverage the versatility that images provide and transform them into a medium with more detail, photogrammetry is a popular method to do the task. With programs like COLMAP[3] and Meshroom[4], the user simply puts in the images of an object and the program tries its best to produce a 3D version of the object using keypoint detection. However, existing programs often require a lot of computational power, and with a push toward edge computing, the need for a lightweight photogrammetry package has never been greater.

2 Design



3 Arduino Rigs

- 3D printed housing and powered by Arduino Unos
- Can communicate to computers via Serial Com
- Used to help accelerate the data collection process

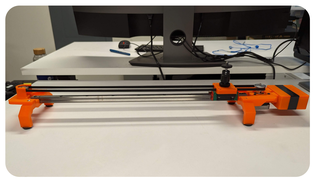


Turntable[5]

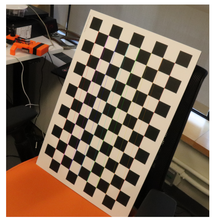
- Has a rotating plate for small objects
- Used to capture all angles
- Camera mounted on an external tripod

Linear Rail[6]

- One meter-long rail
- Camera mount slides across the entire rail
- Used for larger objects (ex. Sofas)



4 Camera Calibration



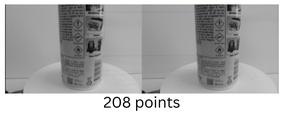
- Extracts camera matrix (3x3) and distortion coefficients
- Camera matrix includes *x* and *y* focal lengths and optical centers
- Distortion coefficients are used to counteract lens distortion

5 Keypoint Detectors

SIFT[7]

- Uses Gaussian Blur[8]
- Oldest and slowest
- Usually extracts most

1657 points



208 points

ORB[9]

- Checks nearby pixels[10] (FAST)
- Runs BRIEF Descriptors
- Relatively fast

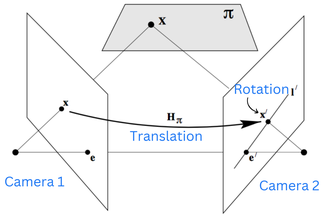
BRISK[11]

- Concentric Rings check[12]
- Intensity Descriptors, similar to ORB
- Relatively fast

547 points

6 Essential Matrix & Recovering Camera Pose

- Essential Matrix: 3x3 matrix that forms epipolar lines

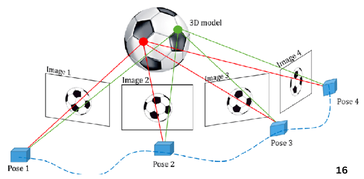


Epipolar lines form a triangle[13]

- Camera Rotation matrix & Translation Vectors recovered
- Coordinates of points in 3D space are also recovered
- 3D points are used to make an initial estimate of point cloud

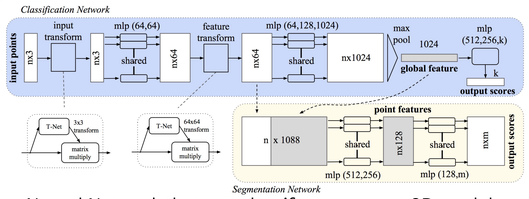
7 Bundle Adjustment & Surface Reconstruction

- BA: Correcting camera pose by reprojecting 3D points to 2D space
- An optimization problem



- Outliers are rejected & faces are created using Poisson[14] or alpha surface reconstruction with Open3D[15]

8 PointNet

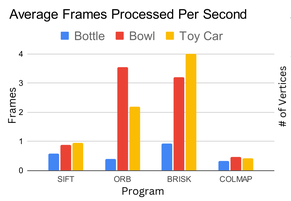


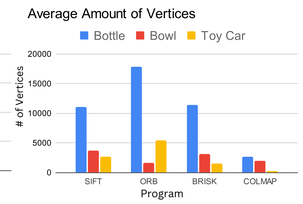
- Neural Network that can classify or segment 3D models
- The model is trained on ModelNet40[17] dataset
  - 40 objects from airplanes to household products
- Used Tensorflow to build and train the model
- PointNet is a quantifiable way to measure quality

9 Data & Results

- Data is obtained by taking pictures or videos of objects
  - Came from a variety of phones and cameras
  - A group of volunteers assisted with data collection
- Benchmarks were performed on a 12-core CPU, 30-core GPU, 32GB RAM ARM-based laptop
- Running COLMAP Sparse as it is the closest equivalent
  - COLMAP Dense reconstruction provides color at the expense of time (> 4 hours)

Perfomance Tests





Accuracy Rate using PointNet Validation	
BRISK	0%
ORB	27%
SIFT	0%
COLMAP	0%

Performance Test on Can w/ 100 images		
	RPi 4B (8GB)	Laptop
BRISK	0:14:39	0:01:09
ORB	0:28:09	0:03:52
SIFT	2:53:53	0:17:10

Raspberry Pi 4B

Specs[18]:

- 1.5GHz Quad Core ARM processor
- 8GB RAM
- Size of a credit card

Sample Outputs

Sample Image

ORB with Alpha Recon

SIFT with Alpha Recon

BRISK with Alpha Recon

COLMAP Sparse

COLMAP Dense

*BRISK failed to run 5 of the datasets, COLMAP failed to run 4 of the datasets

10 Conclusions

- ORB and BRISK have more efficient ways of keypoint extraction
  - Faster than SIFT & COLMAP
- ORB is more reliable than BRISK as it is able to go through all datasets during testing
  - Vertex count seems to be close to each other
- ORB provided mesh that was relatively close to the original mesh
  - Only program to get correct predictions with PointNet
- COLMAP's speed can be contributed to additional computations
- Runs on Raspberry Pi successfully
  - It does take longer, which is expected for the power
  - Opens possibility for edge computing uses

11 Discussion

- PointNet may not be robust against noise
  - ModelNet 40 dataset included a wide range of perfect meshes
  - Adding noise during training could help boost the accuracy rate
  - One of the best tools that can quantify mesh quality
- COLMAP uses SIFT for keypoint detection
  - Explains the similarity in speed
  - However, COLMAP uses significantly more resources, with upwards of 25GBs of RAM used during sparse reconstruction
  - Dense reconstruction can take hours and requires dedicated GPUs
- The package can successfully run on low-powered hardware
- The package provides solid reconstruction faster than existing implementations
  - With accuracy at times even better

12 Future Direction

- Would like to have time to do more extensive testing on mobile hardware
  - Preliminary tests on a Raspberry Pi 4B have shown the same quality of reconstruction at a slower pace
- Use a different implementation of Bundle Adjustment
  - GTSAM bundle adjusts with landmarks and factor graphs
- Implement into real-world applications
  - Interesting to see this project in fossil categorization and defect detection
- Comparing results with LiDAR using PointNet
  - LiDAR uses laser scans -> more accurate

References

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