University of Massachusetts
UMASS Lowell

Structural Engineering Research Group (SERG)
Summer Seminar Series #11
Lowell, Massachusetts
Wednesday August 19, 2015

Photogrammetric 3D Modeling

Nicolas D'Amico

Undergraduate Research Assistant
Department of Civil and Environmental Engineering
The University of Massachusetts Lowell
Lowell, Massachusetts

SERG

Outline

- **Introduction**
- **Objective**
- **Background**
- **Approach**
  - Photogrammetry
  - Image Capturing
    - Aerial Nadir
    - Targeted Oblique
  - Solidworks Models
  - Point cloud and Mesh
- **Applications**
- **Results**
- **Discussion and Summary**
- **Acknowledgement**
- **References**

Introduction

▪ Civil Infrastructure Deterioration

- As Civil engineers across America struggle to push back the dividend of a necessary investment, new techniques need to be brought to light and old ones need to be reformed.

- **D: "POOR: AT RISK**

Category	1988*	1998	2001	2005	2009	2013
Aviation	B-	C-	D	D+	D	D
Bridges	-	C-	C	C	C	C+
Dams	-	D	D	D+	D	D
Drinking Water	B-	D	D	D-	D-	D
Energy	-	-	D+	D	D+	D+
Hazardous Waste	D	D-	D+	D	D	D
Inland Waterways	B-	-	D+	D-	D-	D-
Levees	-	-	-	-	D-	D-
Public Parks and Recreation	-	-	-	C-	C-	C-
Rail	-	-	-	C-	C-	C+
Roads	C+	D-	D+	D	D-	D
Schools	D	F	D-	D	D	D
Solid Waste	C-	C-	C+	C+	C+	B-
Transit	C-	C-	C-	D+	D	D
Wastewater	C	D+	D	D-	D-	D
Ports	-	-	-	-	-	C
America's Infrastructure GPA	C	D	D+	D	D	D+
Cost to Improve	-	-	$1.3 trillion	$1.6 trillion	$2.2 trillion	$3.6 trillion

**The first infrastructure grades were given by the National Council on Public Works Improvements in its report Fragile Foundations: A Report on America's Public Works, released in February 1988. ASCE's first Report Card for America's Infrastructure was issued a decade later.*

Fig 1 :(**Source**: ASCE 2013 infrastructure report card.)

Introduction

- ## Civil Infrastructure Deterioration
  - On April 8, 2015 the MBTA submitted an action plan which called for the transformation of the MBTA due to what they describe as "pervasive structural failures"

MBTA Reported:

Asset Category	# of Assets	Replacement Value	SGR Score	SGR Backlog Amount	% of Total Backlog
Revenue Vehicles	20,262	$6,807,342,488	2.83	$2,634,418,286	39.4%
Bridges	1,335	$5,148,275,301	3.39	$799,663,040	11.9%
Signals	401	$2,900,740,296	2.57	$1,369,027,122	20.5%
Stations	50,054	$2,699,874,652	3.86	$255,984,809	3.8%
Facilities	2,855	$1,527,289,845	3.19	$477,930,928	7.1%
Track/ROW	129	$823,254,368	2.69	$304,603,884	4.6%
Power	3,047	$793,073,100	2.18	$462,319,775	6.9%
Parking	47,215	$228,188,855	2.12	$172,050,515	2.6%
Communications	15,334	$172,916,740	4.25	$3,195,090	0.0%
Technology	1,092	$138,231,180	1.39	$131,592,980	2.0%
Tunnels	67	$132,750,000	3.10	$24,000,000	0.4%
Non-Revenue Vehicles	1,089	$77,414,330	2.70	$33,724,000	0.5%
Fare Collection	2,982	$64,152,548	3.79	$425,000	0.0%
Elevators and Escalators	338	$49,370,000	2.94	$22,950,000	0.3%
	146,200	$21,562,873,703	3.05	$6,691,885,429	100%

Source: MBTA

Fig 2 : (**Source:** MBTA Panel Report)

"Some have called the winter of 2015 a 'stress-test' for the MBTA. While the MBTA 'survived' the test, short-term costs were significant in disruption, economic losses, and public and private hardship. The long-term costs are even more troubling: the loss of public confidence in our regional transit system." (MBTA panel report)

Introduction

- **Civil Infrastructure Deterioration**

  - On July 10th, 2015 a piece of debris fell from the Commonwealth Ave. in Boston down to Mass Ave below

Fig 3: (**Source:** The Boston Herald (photo by Chitose Suzuki))

Introduction

- ## Civil Infrastructure Deterioration

  - "Most of our road, rail, water, sewer, electric power, wired telephone, and other distributed systems infrastructure are old and in need of repair. Our ports, airports, and rail terminals are archaic, ill designed, badly run, and *poorly maintained*. Levees, coastal defenses, and dams often **lack effective inspection and maintenance**" (Ernst. G Frankel America's Infrastructure Ernst G. Frankel Engineering Dilemma, M.I.T Faculty newsletter, Vol. XX No. 1 September/October 2007)

Fig 4: (**Source:** Sustainable Cities Collective, website)

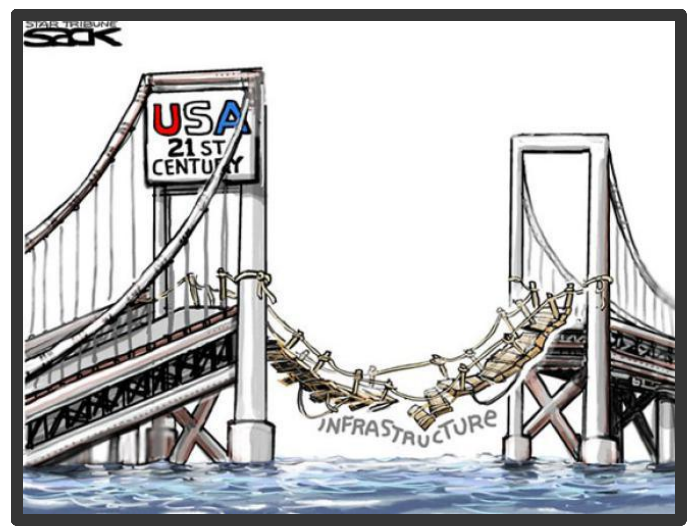


Fig 5: (**Source:** Steve Sack politic Cartoonist Star Tribune)

Objective

- To establish guidelines for the safe, and routine maintenance inspection of Civil infrastructure systems using photogrammetric techniques to qualitatively and quantitatively evaluate the level of risk and need for maintenance of a given civil system.

Background

- **Photogrammetry is :**

The art or science of taking 2D information and compiling it into 3D information

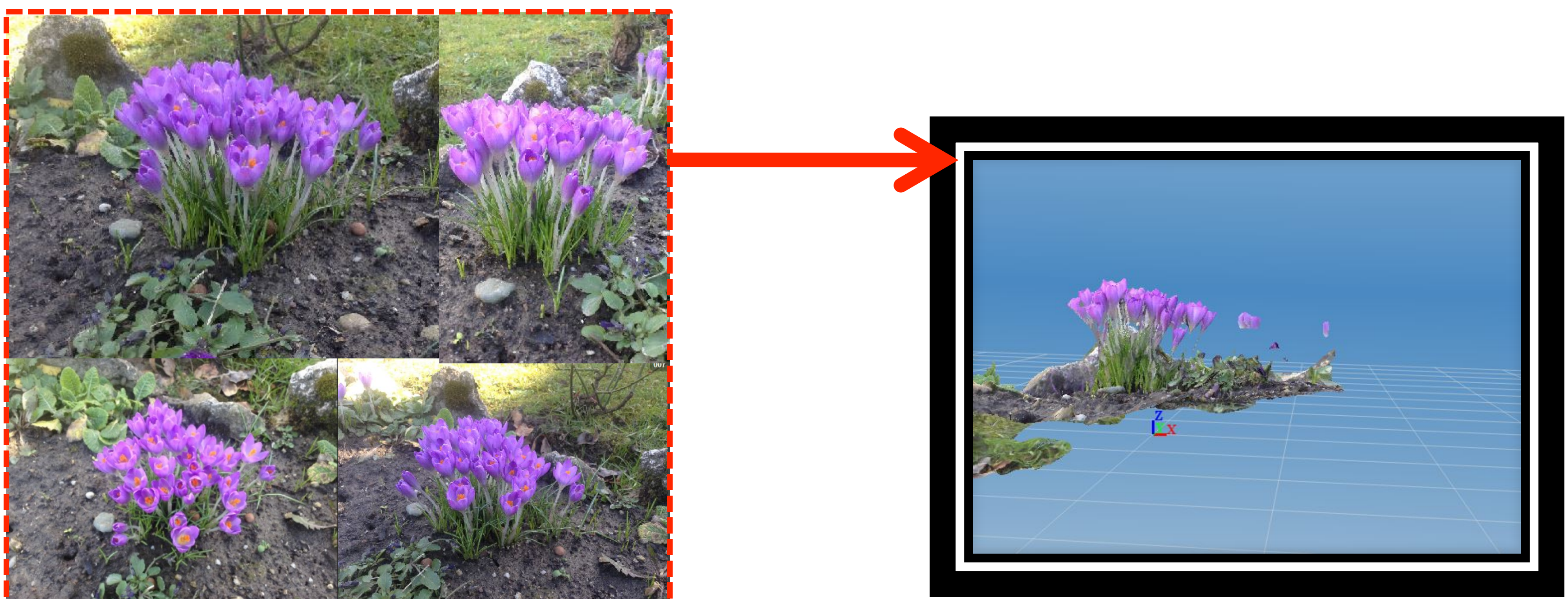


Figure 6 : Pictures into model (**source:** 123D catch model gallery)

Background

- (1400s), Photogrammetry First displayed itself as an art and science during the renaissance many renaissance painters studied perspective geometry, they integrated mathematical information about depth and spatial recognition into their artwork.

- "The art of perspective is of such a nature as to make what is flat appear in relief, and what is in relief flat" (Leonardo Da Vinci, The notebooks of Leonardo Da Vinci 41)

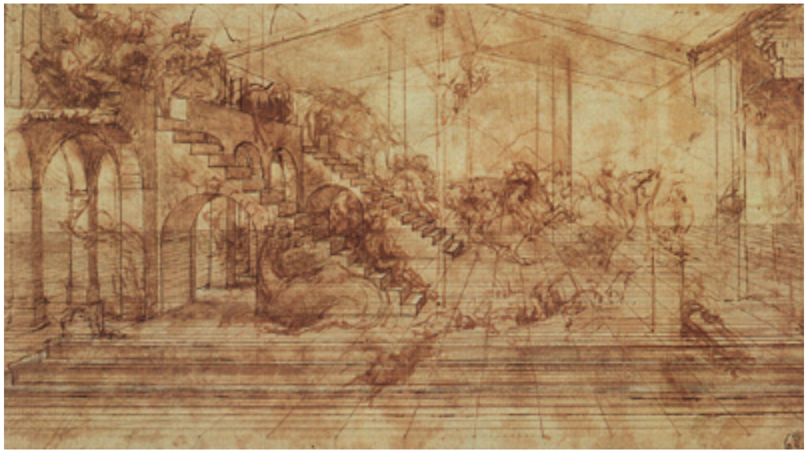


Fig 7: Leonardo da Vinci, perspective drawing for The Adoration of the Magi (**Source:** Art history resources)

Background

- (1648) Girard Desargues opens the scientific field of projective geometry with his theorem Desargue's Theorem which identifies a center of perspective and axis of perspectivity.

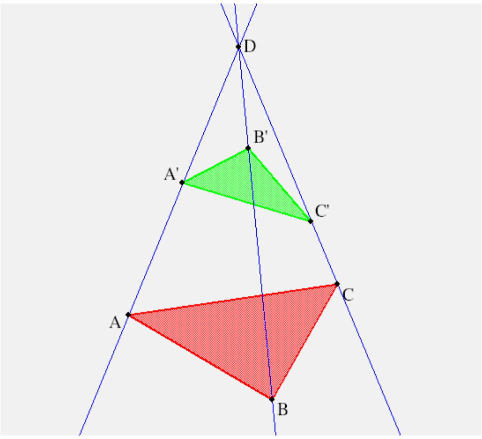


Fig 8:Desargues Theorem (**Source:** http://new.math.uiuc.edu/)

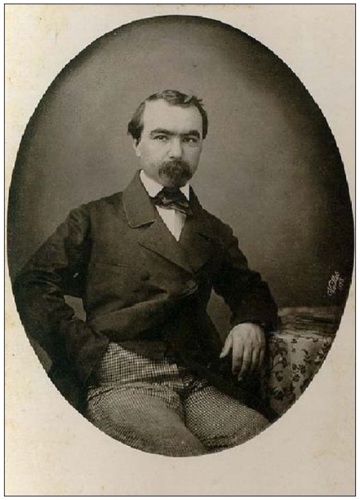


Fig 9: Aime` Laussedat (**Source:** Wiki- public images)

- (1849) Aime` Laussedat develops Metrophotography, which is photographic surveying for maps. Coined as the *father of photogrammetry*

Approach

- **Image Capturing**
  - Image collection techniques are broken into two key sub-categories.
  - **Nadir** and **Oblique** Photogrammetry

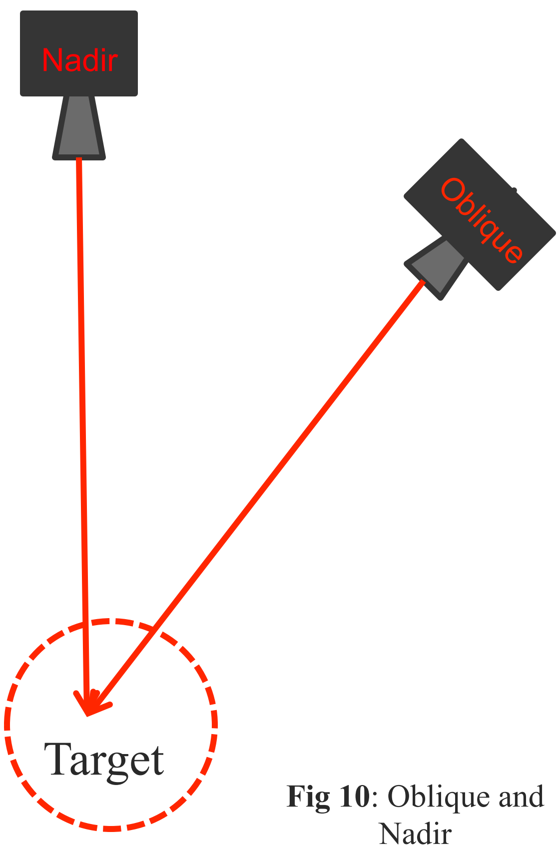


Fig 10: Oblique and Nadir

Approach

- **Image Capturing**
  - **Nadir- Aerial** is image taking from directly above (90⁰) the Point of interest
  - This approach is meant for aerial mapping of large areas rather than singular structures, and is thereby effective for imaging of large masses of land.
  - Most of the current UAV Photogrammetry is in this fashion

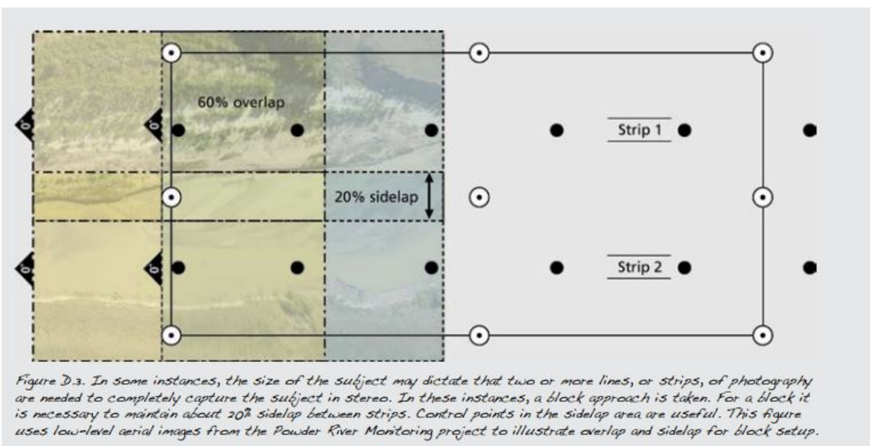


Figure 11: Forward Overlap **(Source**: Beaurea of land Management)

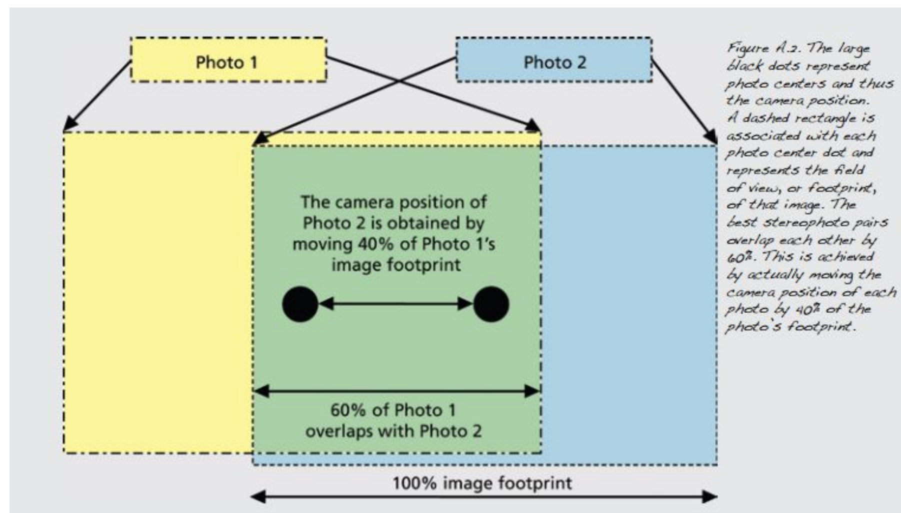


Figure 12: Side Overlap (**Source:** Beaurea of land Management)

Approach

- ## Image Capturing
  - **Oblique Targeting** is image capturing aimed (obliquely) at one structure and uses multiple image perspectives and angels to triangulate and calculate dimensions.
  - If the oblique angle is too acute the image is lacking a lot of spatial recognition. Between 30º- 45º is recommended.

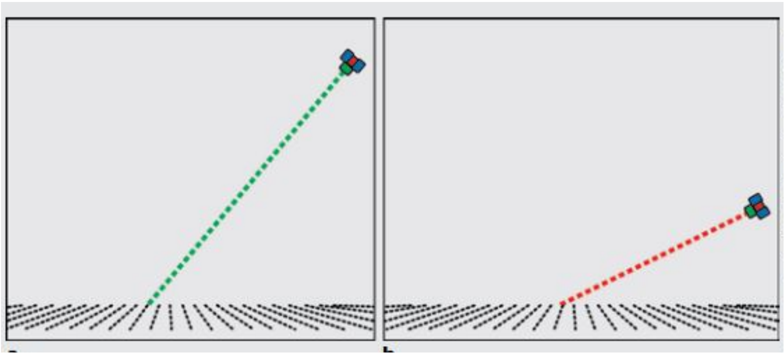


Figure 13: Oblique angles(**Source:** Beaurea of land Management)

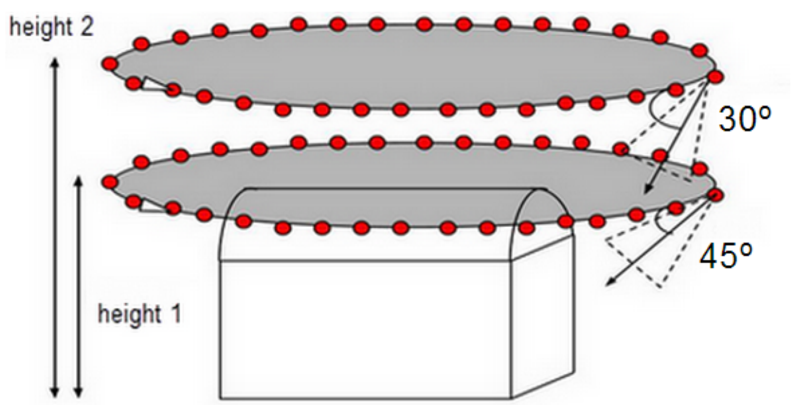


Figure 14 : Oblique Overlap(**Source:** Pix4d support website)

Approach

- 123D catch and other photogrammetric modeling software's use key points to match images to start creating the models. This means that their needs to be overlap in the images. Overlap is essential for images to work collaboratively. This work is done manually for solidworks generated models

Photogrammetric modeling calls for about 70% front and 30% side overlap

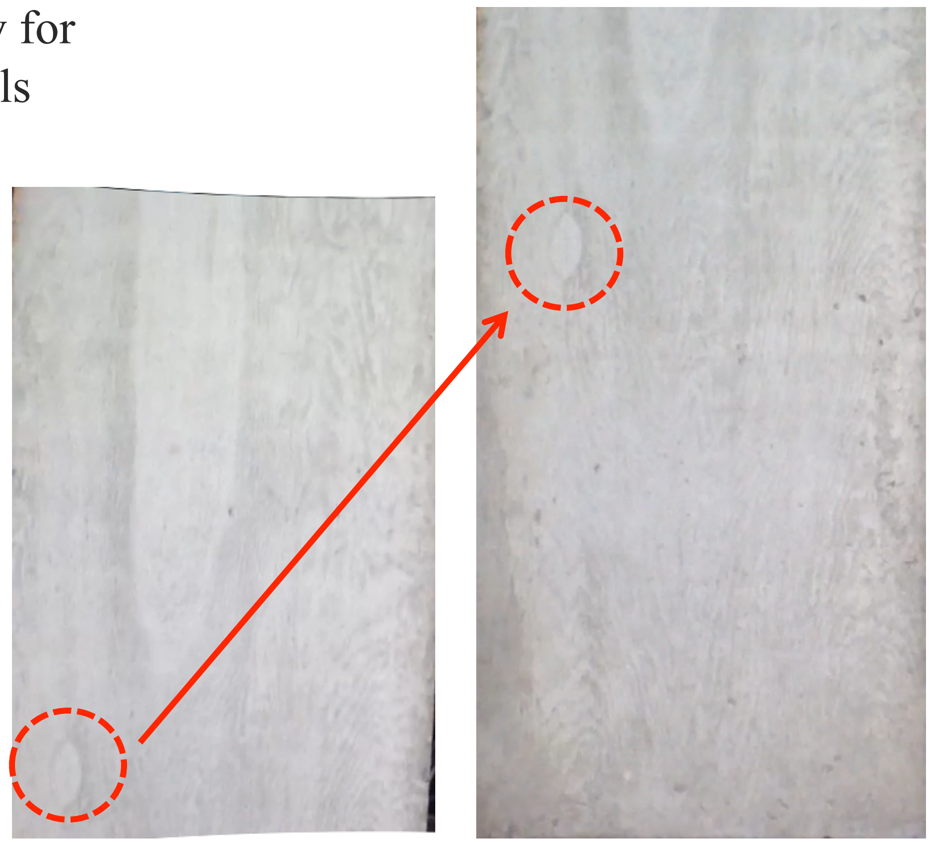


Figure 15: Alignment using Key points

Approach

- **Depth** is the in or out of plane distances in a 2D image. Or the imaginary third dimension in a flat picture

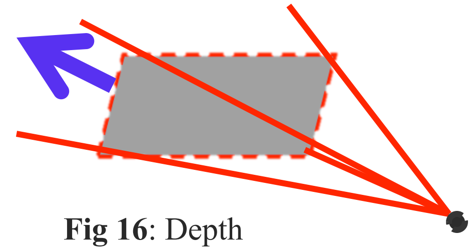


Fig 16: Depth

- In a single 2D image depth perception is a non quantifiable illusion. It is however possible to use multiple perspectives to create a stereo depth perception.

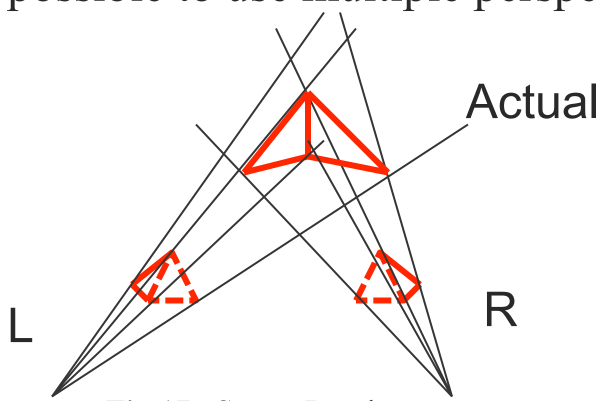


Fig 17: Stereo Depth

- By locating all of the differences between two identical points in an image it is possible to start location 3D information which in turn helps create a 3D image.

Approach

- ## Extracting Depth
  - To extract information about depth from photographs we need multiple perspectives. The triangulation of stereovision, allows for computation of depth in the a similar way to that of the human eyes

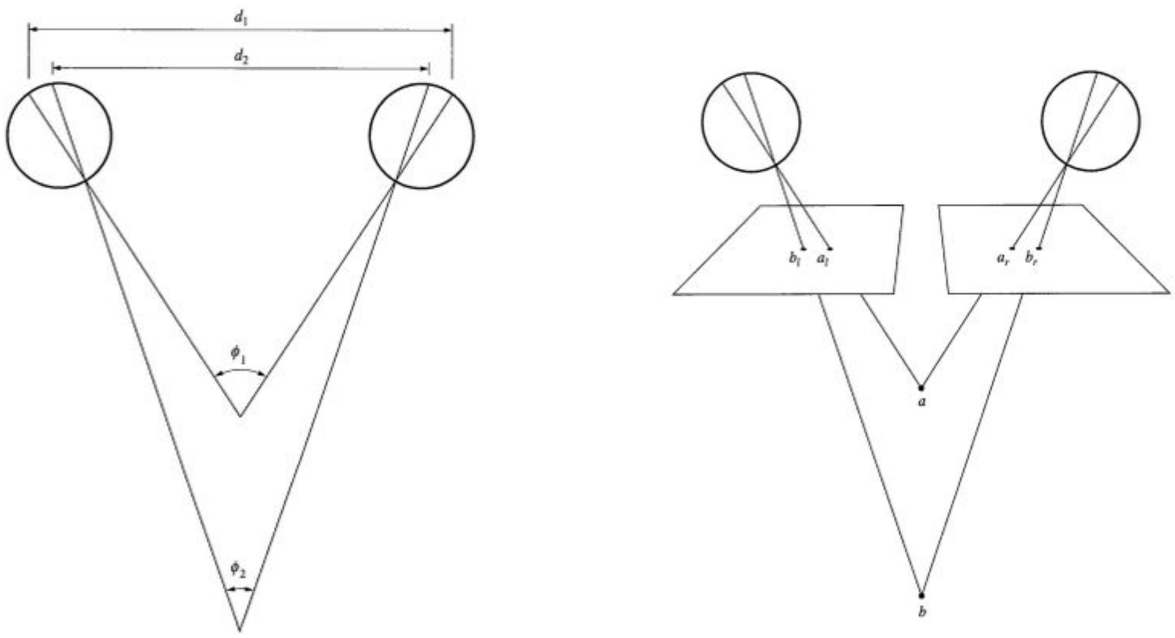


Figure 18: Stereo Vision (**Source:** Introduction to Modern Photogrammetry)

Approach

- ## Extracting Depth
  - The concept of parallax is another way to interpret depth from photographs. Parallax is the relative relationship between distance from perspective, and movement. (I.E.) an object farther away move much slower than objects close by. Parallax and proximity are inversely related. By studying the movement of key points with respect to time the program is able to establish a sense of relative depth.

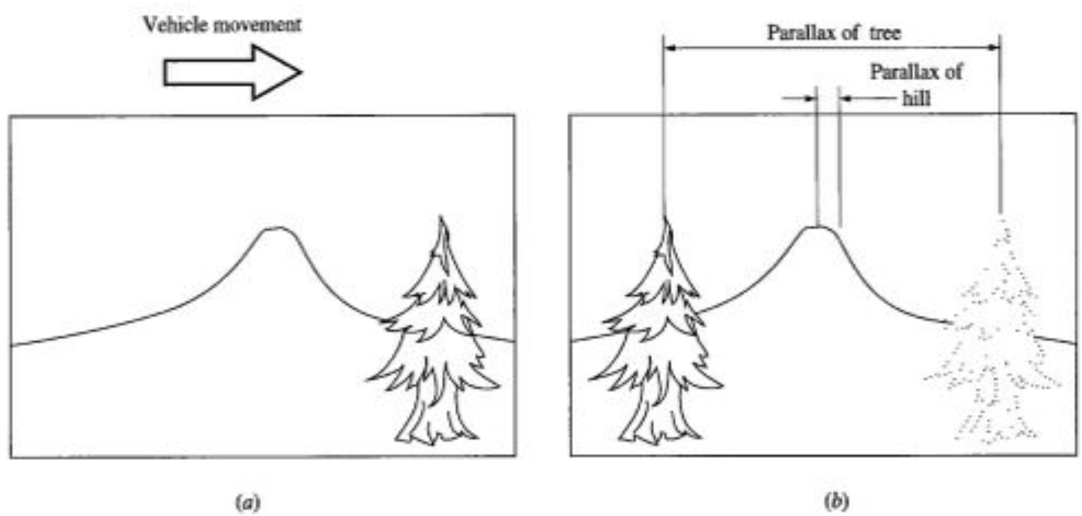
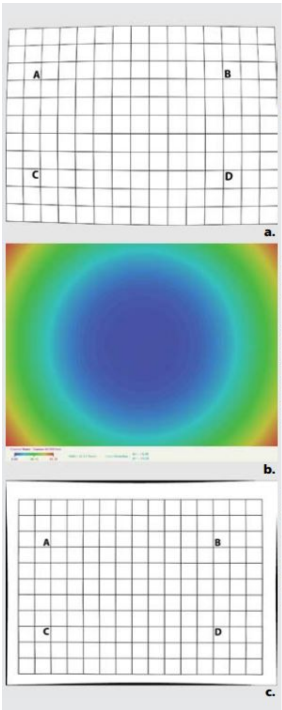


Figure 19: Parallax (**Source:** Introduction to Modern Photogrammetry)

Approach

- **Snells law (refraction) distortion, and resolution**
  - The software's modeling computation must also take into account problems which arise from the refraction of light as it enters the medium of the lens. This refraction modeled after snells law must be corrected for. Certain lenses also have fisheye (radial) distortion, and all have their own resolution. The better camera on the UAV, the better the results will be when the software computes the 3D model.

Figure 20: Radial Distortion (**Source:** bureau of land management)

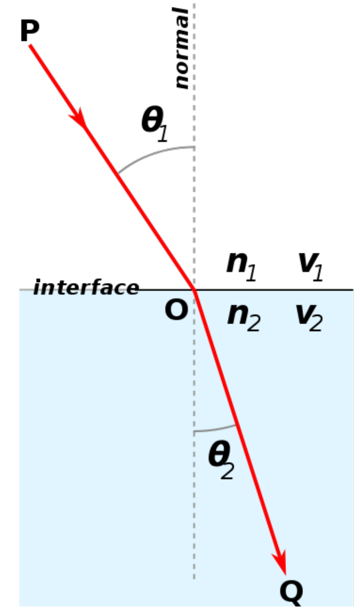


$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}$$

(Snells Law)

Resolution is the ability to distinguish two light sources from another and an image background. It is a representation of the amount of information stored in the image. A high resolution image will contain more pixels, data, and information per square inch.

Figure 21: Refraction According to Snells Law (**Source:** Wiki- public images)



Approach

- ## Calibration of the models scale
  - In order to correctly analyze any of the 3D information found through photogrammetric approaches, a definite scale needs to be implemented. This means correctly defining a known length and defining it in the model.
  - By defining one length, we can thereby define the scale as the aspect ratio of the model is fixed and accurate.

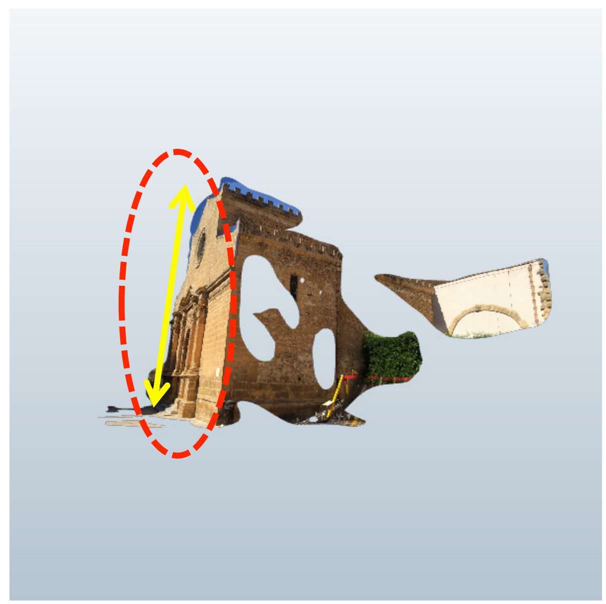


Fig 22 - 23: scale calibration (**Source:** 123D Catch model gallery)

Approach

- **Softwares**
  - **Solidworks™** allows for geometric modeling of columns, structures and walls with applied manual photo-stiching
  - **Cyberlink Photo-editing software™** eliminates fisheye and perspective distortion for manual stitching
  - **123D-Catch (Autodesk)™** key-point generating software which automatically generates a point cloud model
  - **Meshlab™** open-source software that allows for qualitative and quantitative evaluation of point cloud and mesh models

Application

- ## Solidworks Models
  - Concrete Canoe Model
  - Circular Column
  - L-Shaped Column
  - Wall

- ## Point Cloud and Mesh Models
  - Shattered Cylinder
  - Intact Cylinder
  - Olney Receiving Dock
  - Olney Auditorium
  - Pinanski Hall

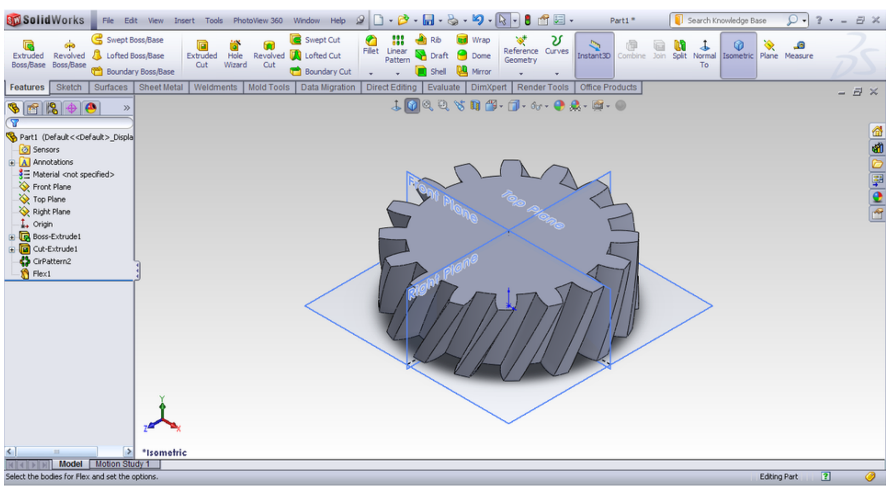


Figure 24: Solidworks Model (**Source:** Solidworks tutorial)

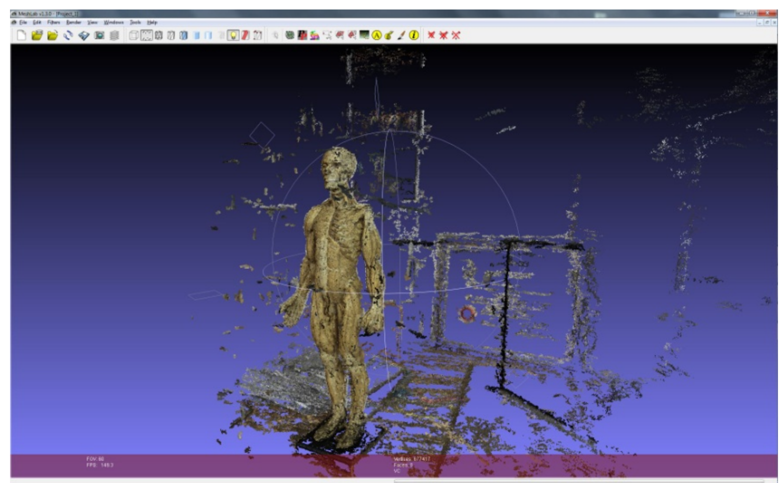
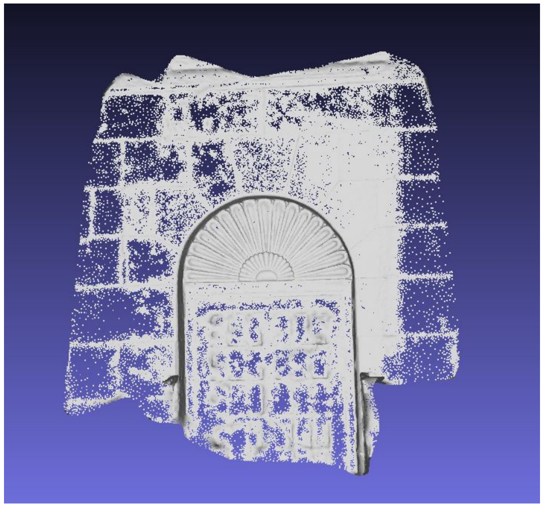


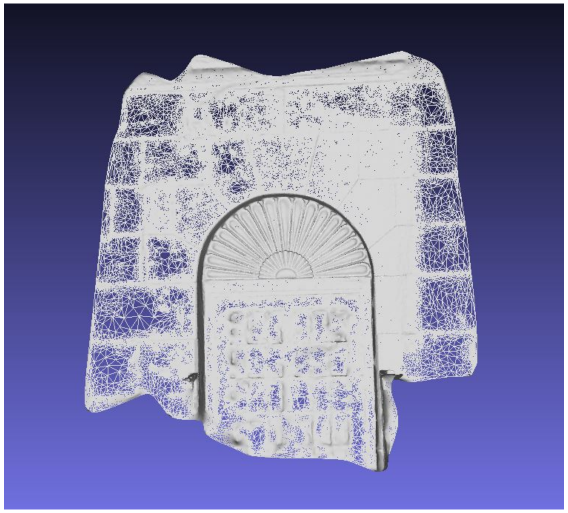
Figure 25: Point Cloud Model(**Source**: Syracuse university design works)

Application

- **What is a Point Cloud?**
  - Once the computation for relative perspective locations start to calibrate, and keypoints are aligned. The software will place points in a relative 3D space which will make up what is referred to as a point cloud model. Triangular mesh from the relationship between points is a Mesh model. And by adding a "texture" of the relative images we establish the final model.



Point Cloud



Mesh

Final

Figures 26-28: point cloud and mesh model (**Source:** 123D catch model gallery)

Results

- **Solidworks Models: Concrete Canoe**

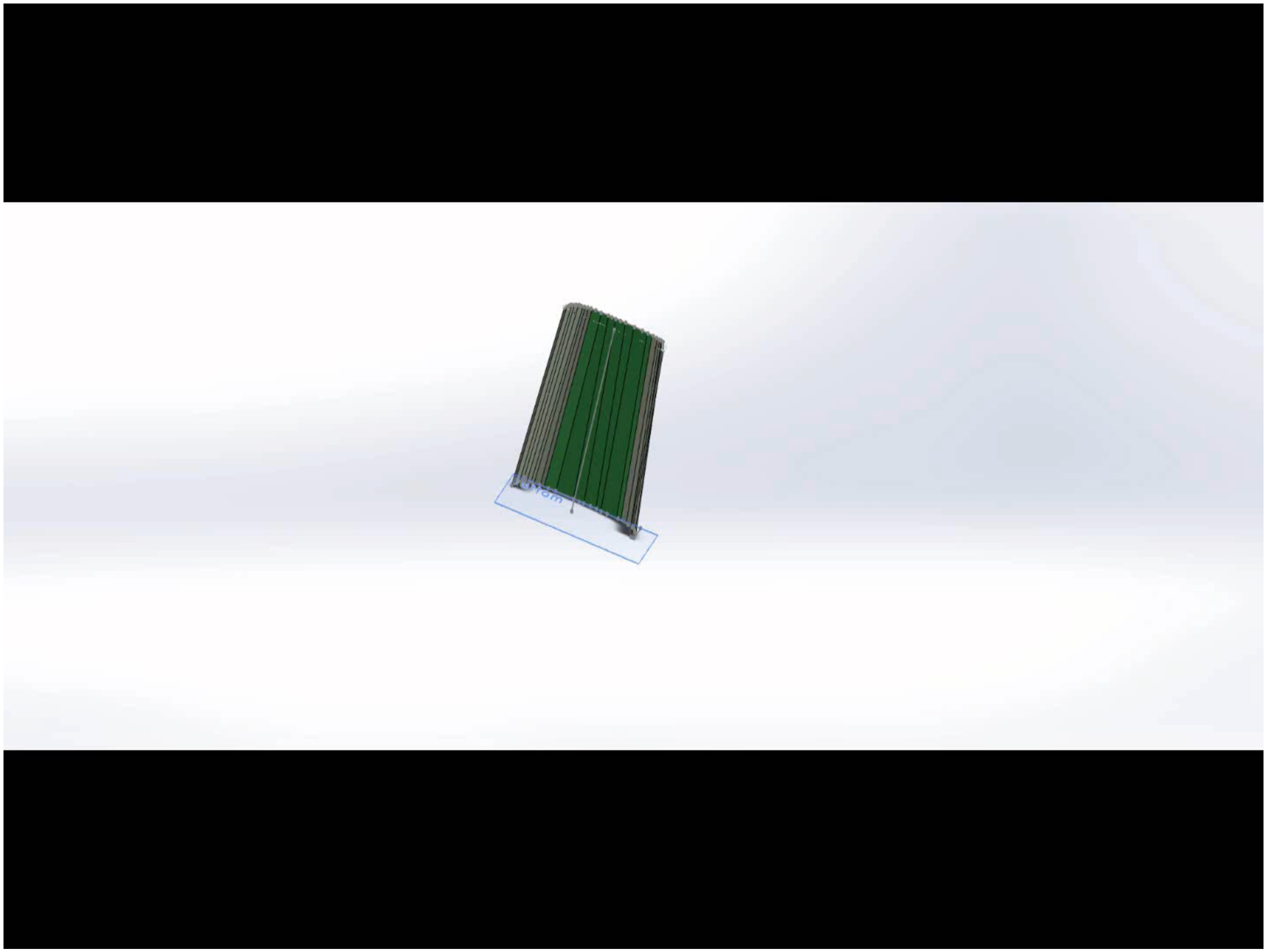


Fig 28: (above) &
Video 1: (left)
Umass Lowell's
Concrete canoe section.
Located in SO122
And

Results

- **Solidworks Models: Columns and Walls**

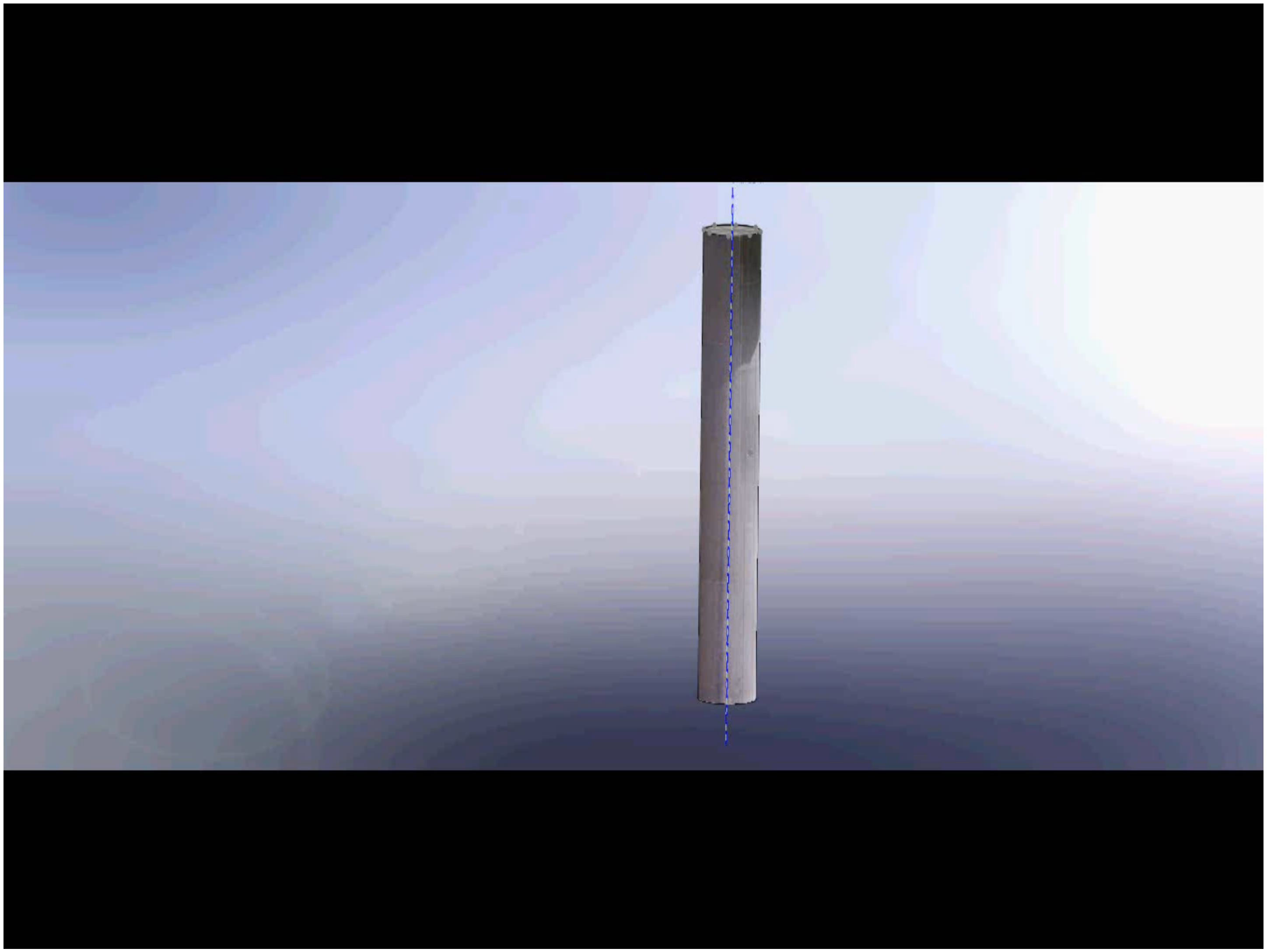
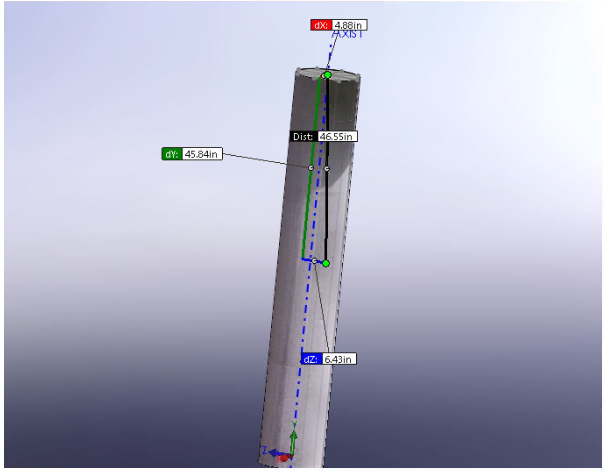
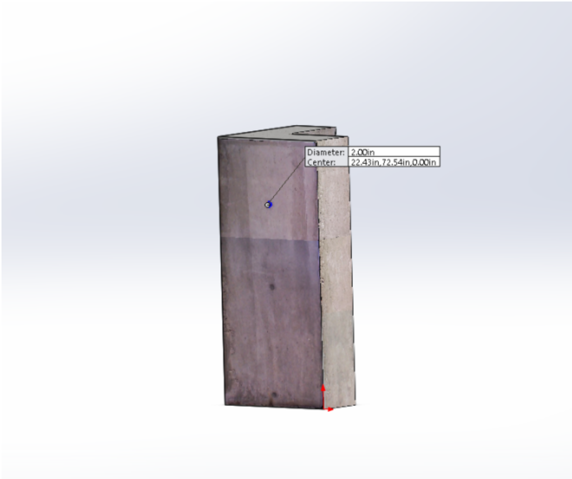


Fig 29: (above) &
Video 2: (left)
Concrete wall and columns on Umass Lowell's South Campus

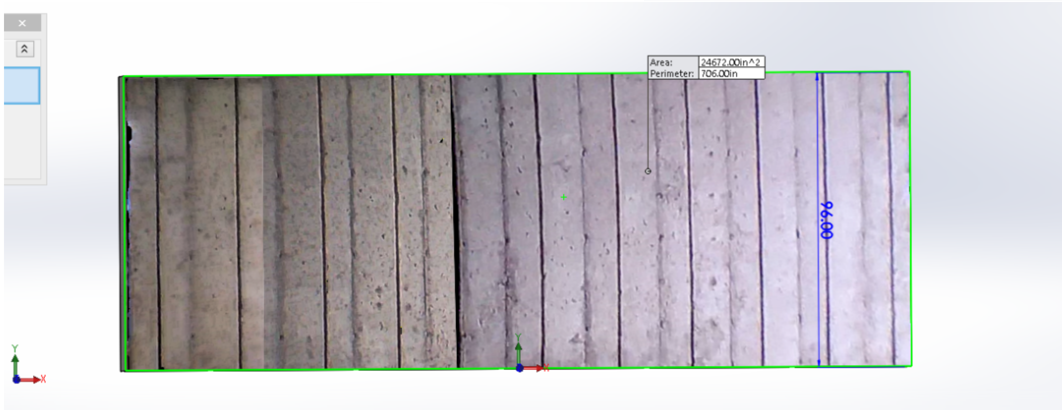
Results

- **Solidworks Models:**
  - Once uploaded into Solidworks 3D modeling and computational software the Models can by qualitatively as well as quantitatively evaluated.





Limitation of manual stitching and modeling on complicated structures.



Figures 30-32 : Solidworks evaluation techniques

Results

- **Point Cloud and Mesh Models: Crushed Cylinder**

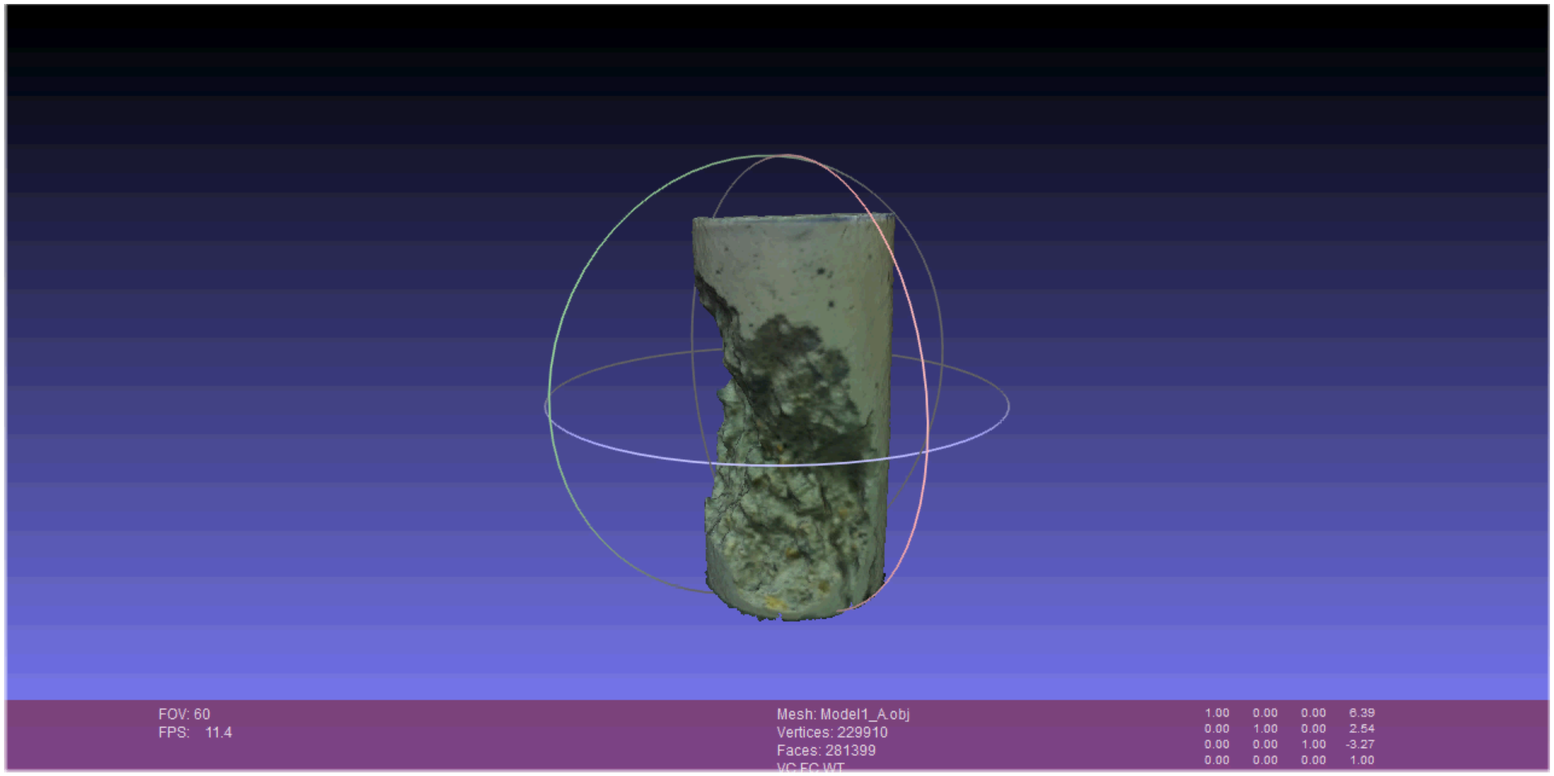
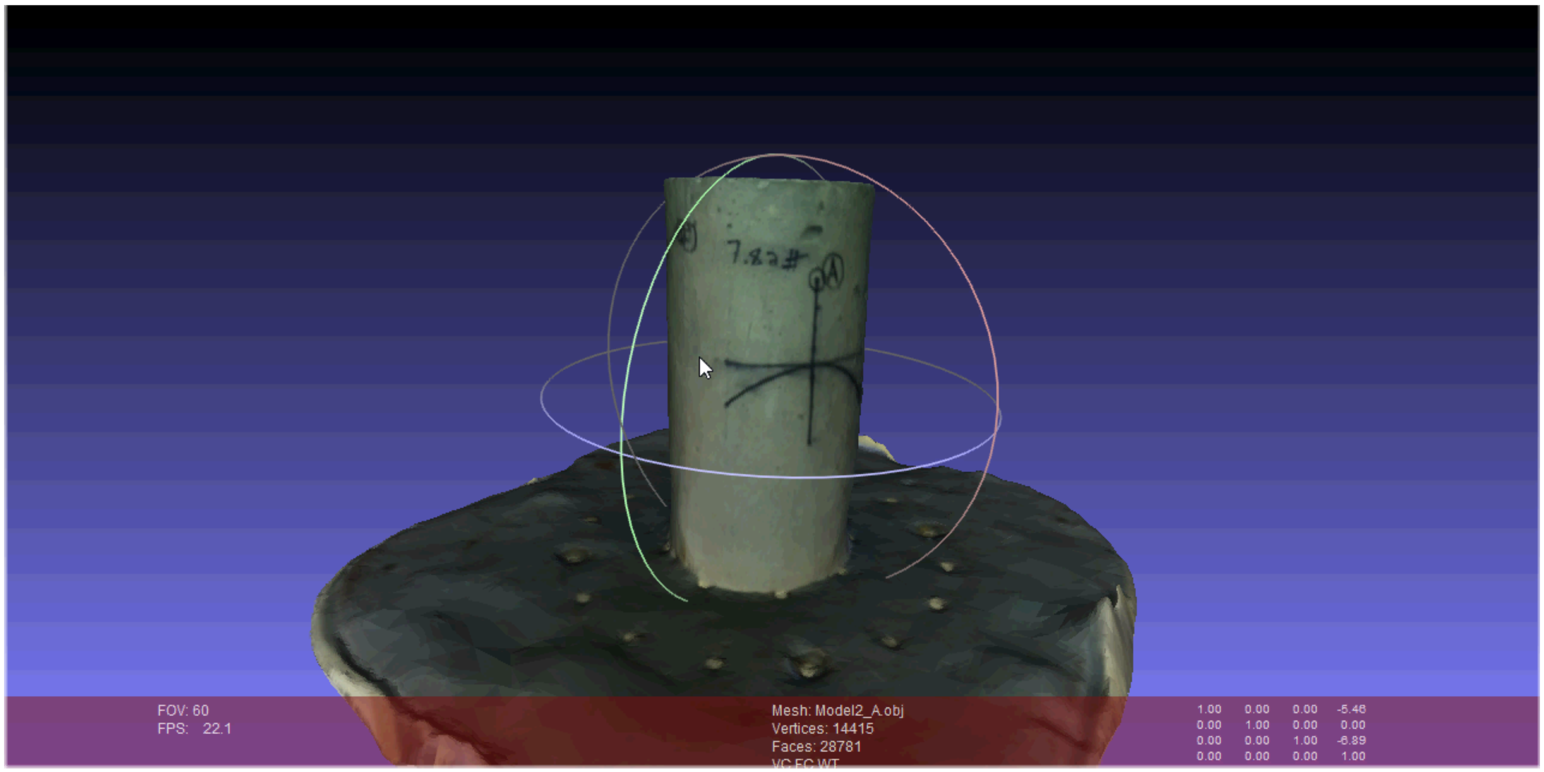
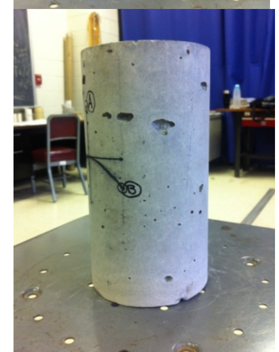


Fig 31-33: (right) &
Video 3: (left)
Shattered concrete
cylinder

Results

- **Point Cloud and Mesh Models: Intact Cylinder**





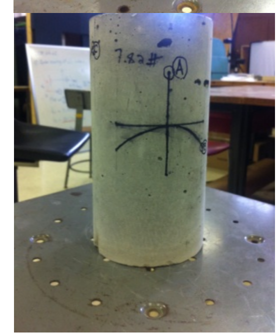


Fig 34-36: (right) &
Video 3: (left)
Intact concrete cylinder

Results

- Can we tell what we are looking at? How easy is it to identify the target/defect

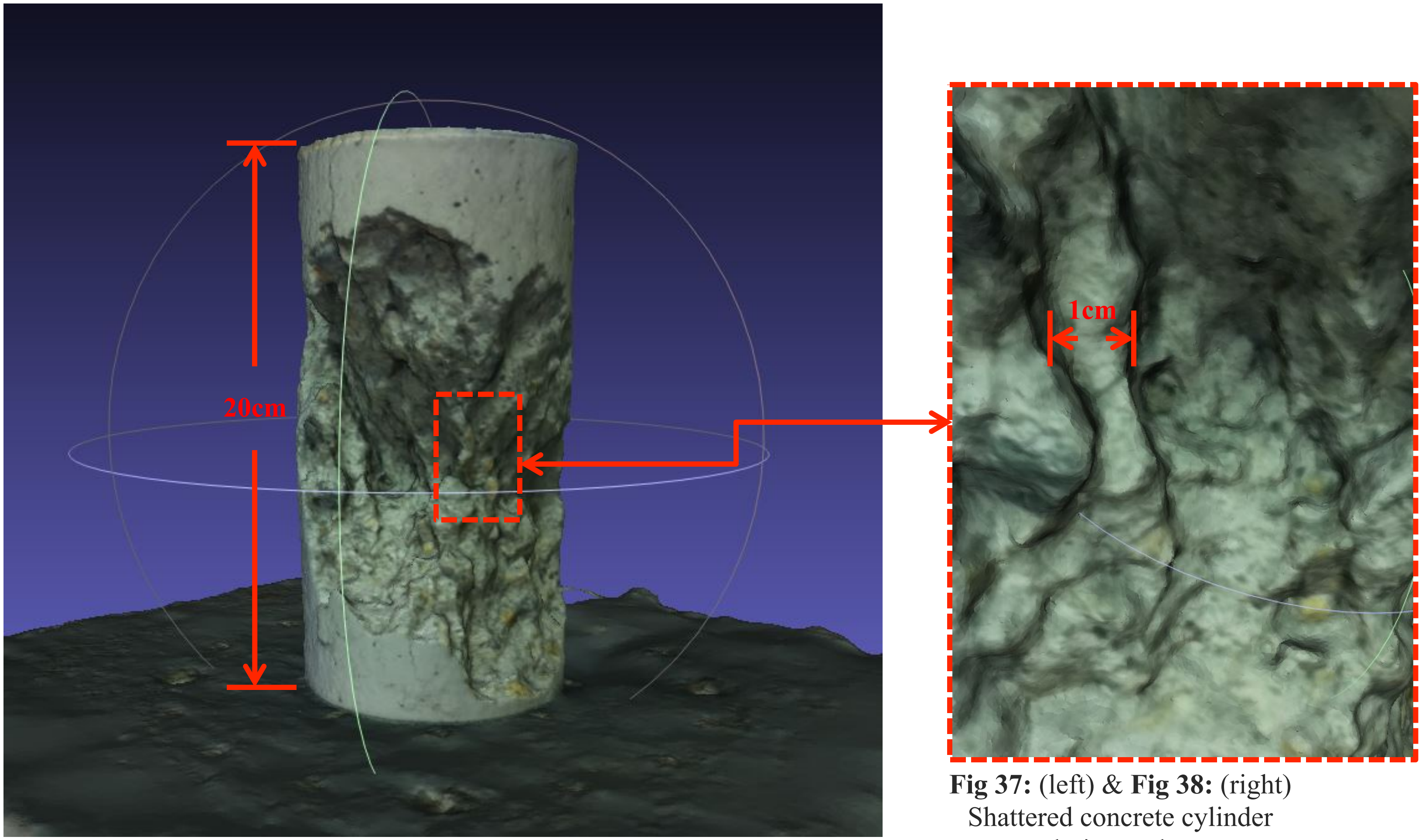


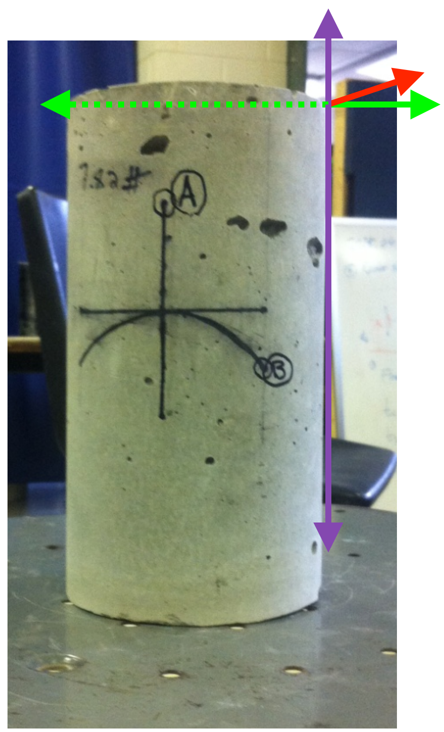
Fig 37: (left) & **Fig 38:** (right)
Shattered concrete cylinder resolution and zoom

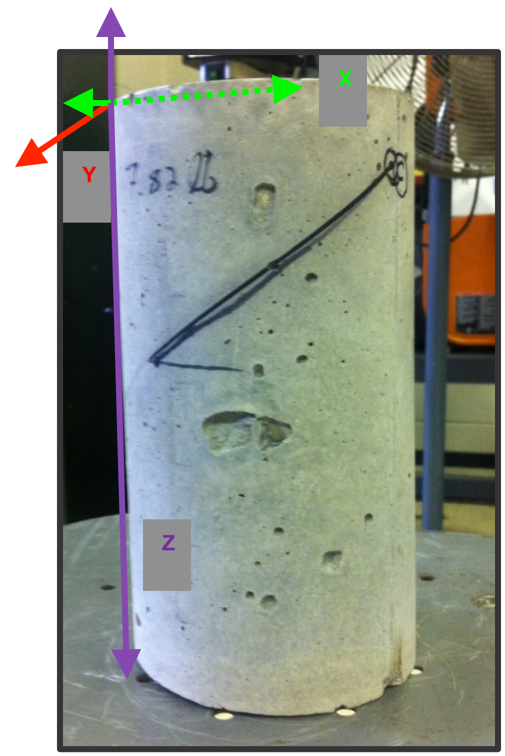
Results

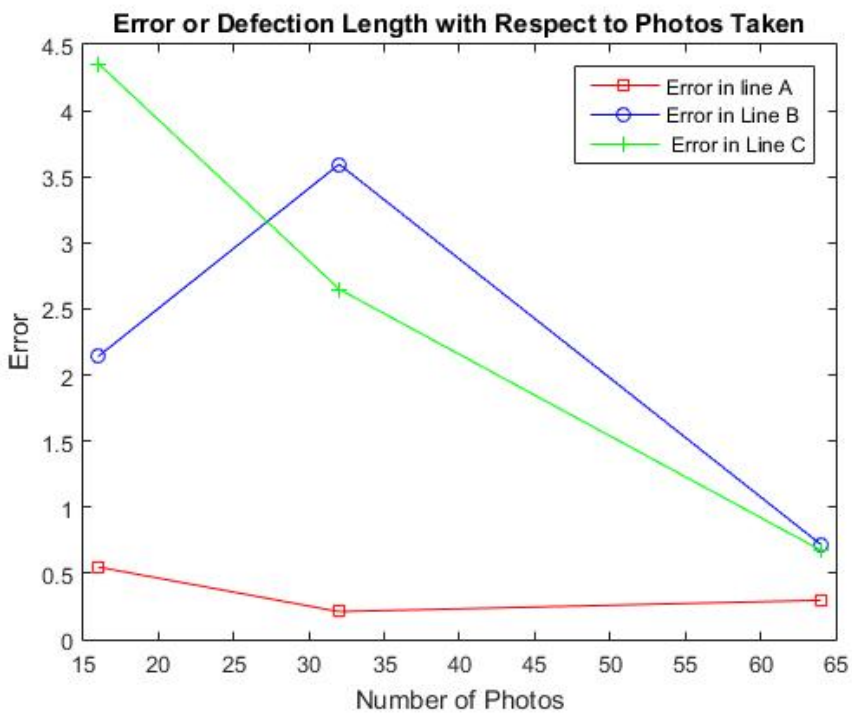
- ## Data Comparison

Table 1

Model	Photos	Lines		
		Error A: (%)	Error B: (%)	Error C: (%)
I	64	0.296	0.718	0.675
II	32	0.210	3.594	2.649
III	16	0.548	2.142	4.356
IV	12	N/A	N/A	N/A





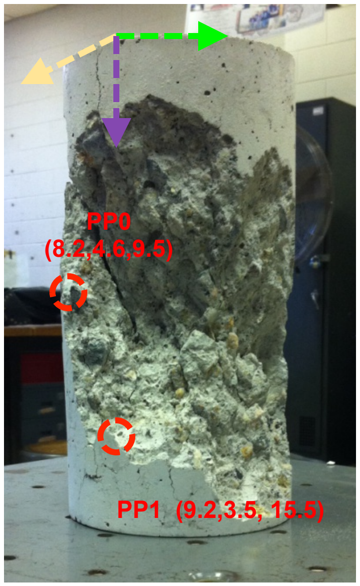


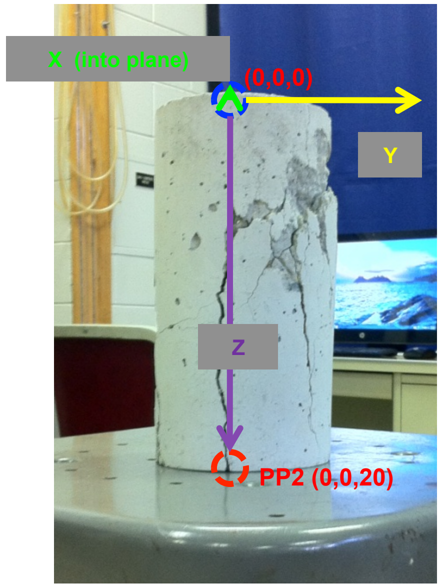
"Line segments have position, orientation and length. Usually the orientation of a line is the least influenced by noise and its length is most influenced by noise" (Goshtasby)

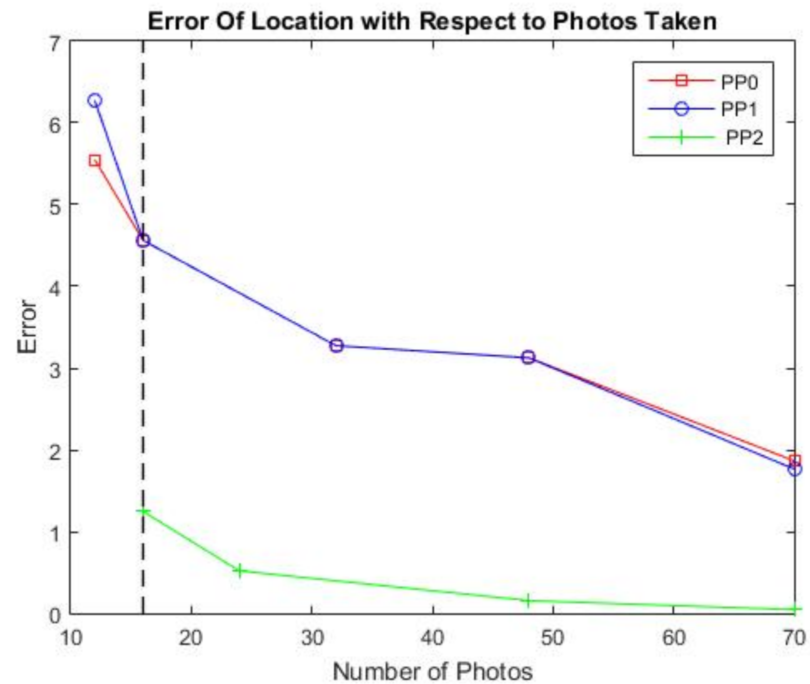
Fig 39: (left) & **Fig 40:** (right) Intact concrete cylinder lines A-C and axis
Fig 41: (Graph)

Results

- ## Data Comparison







Actual	Position		
PP0	8.2	4.6	9.5
PP1	9.2	3.5	15.5
PP2	0	0	20

Error (%)

Photos	PP0	PP1	PP2
70	1.864843	1.765006	0.043635
48	3.126207	3.12451	0.154672
32	3.273844	3.273844	0.518227
16	4.563256	4.563256	1.245197
12	5.549914	6.27514	n/a

Fig 42: (left) & **Fig 43:** (right)
Shattered concrete cylinder
point 0-2 and Axis
Fig 44: (Graph)

Results

- **Can we accomplish the same task with larger structural targets, and how does light effect the results?**

Fig 45: (left) Olney auditorium
Fig 46: (Center) Olney receiving dock
Fig 47: (right) Pinanski hall

Results

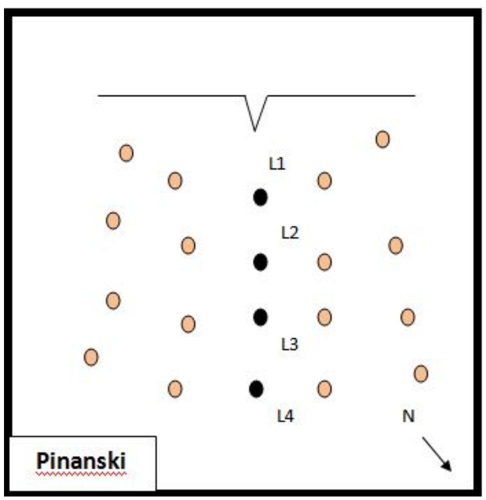
▪ Photogrammetric Light Study

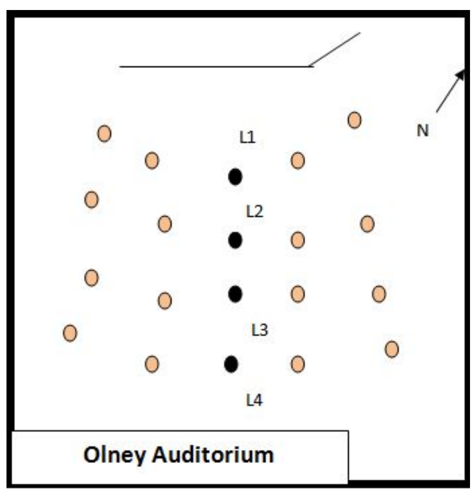
Table 2

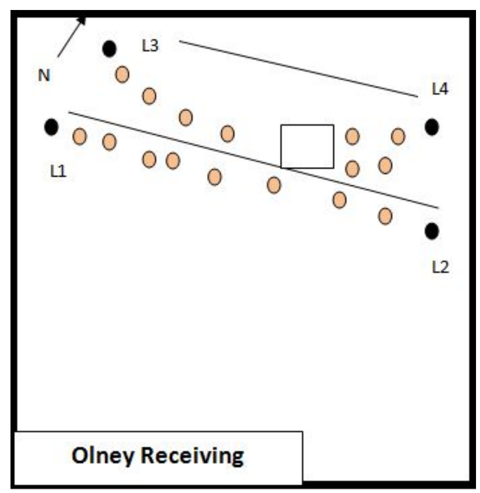
Location	Distance(m)	Time (of day)	Light Intensity (lux)
L1 (Pinanski)	3.67	1:38pm	**86x100**
L2 (Pinanski)	5.87		
L3 (Pinanski)	7.98		
L4 (Pinanski)	13.57		
L1 (Olney Auditorium)	4.27	1:47pm	**213x100**
L2 (Olney Auditorium)	7.29		
L3 (Olney Auditorium)	9.74		
L4 (Olney Auditorium)	13.38		
L1 (Olney Receiving)	19.86	1:56pm	**48x100**
L2 (Olney Receiving)	8.52		
L3 (Olney Receiving)	4.67		
L4 (Olney Receiving)	7.67		

For each target, 20 photos were taken systematically at 4 relative distances

Fig 48: (left) Pinanski
Fig 49: (Center) Olney auditorium
Fig 50: (right) Olney receiving dock







Results

- Olney Auditorium (213 x 100) Lux at target

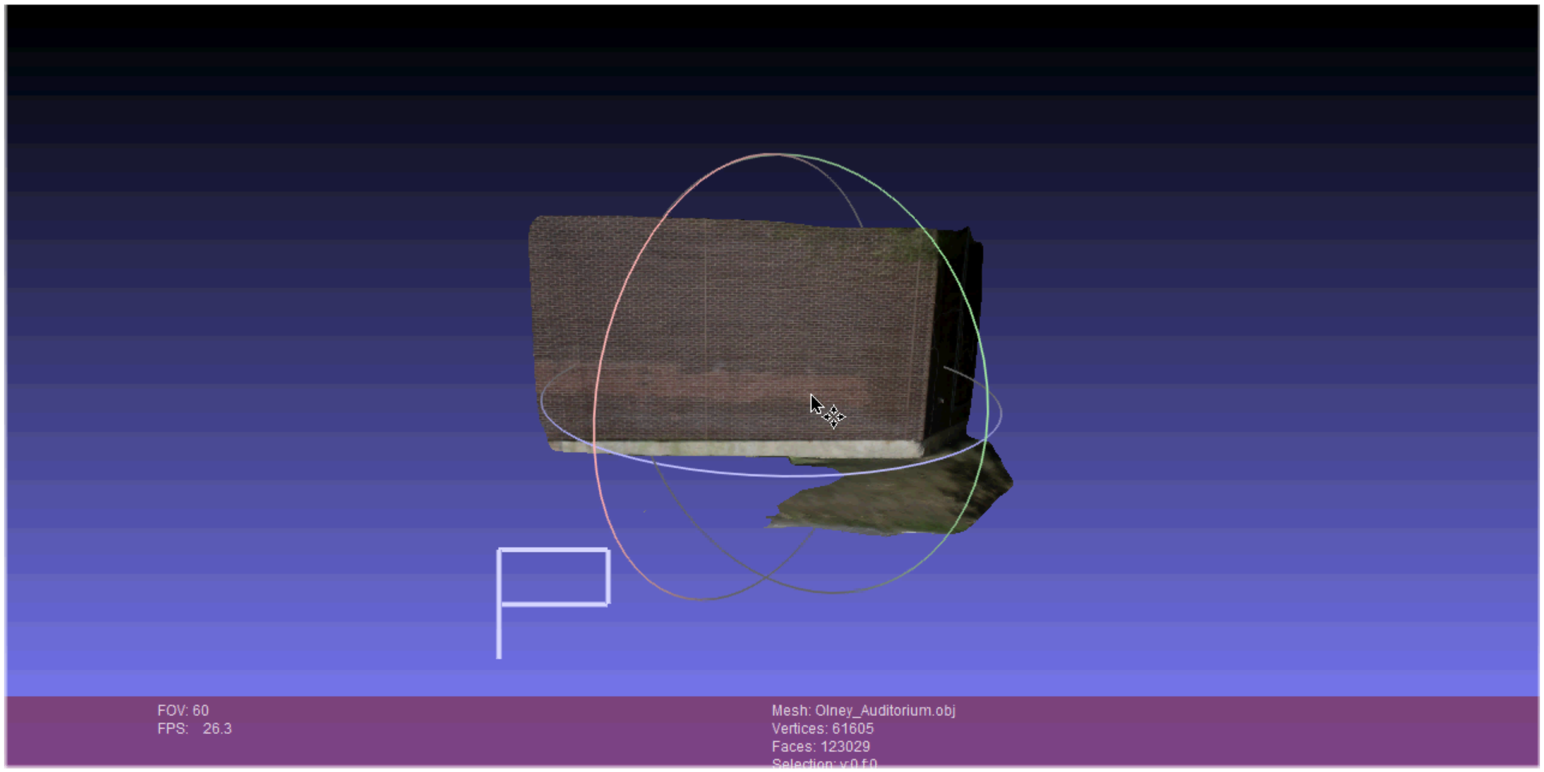


Fig 51: (left) &
Video 3: (above)
Olney Auditorium

Results

- Pinanski (86x100) Lux at target

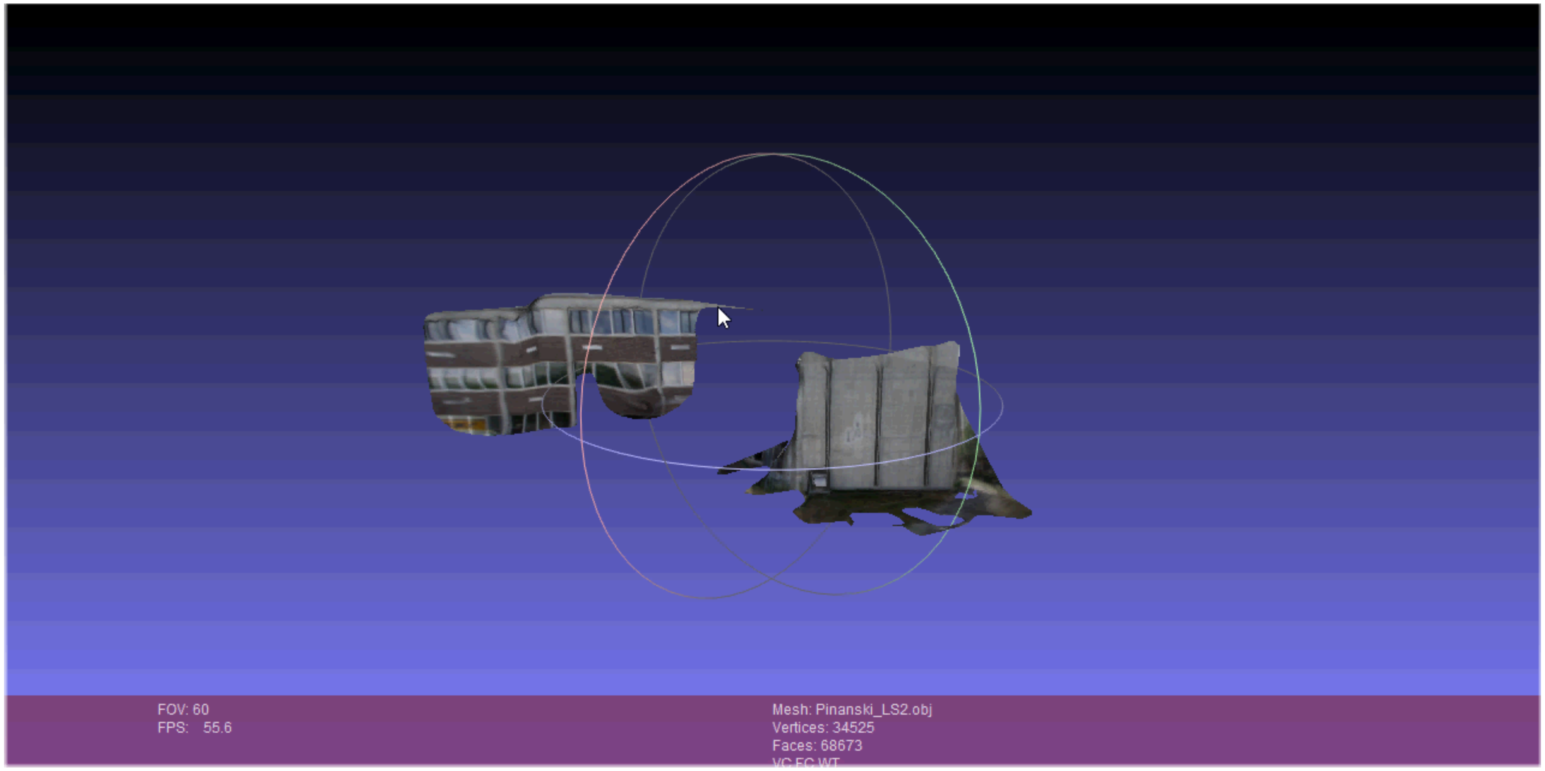


Fig 52: (left) &
Video 4: (above)
Pinanski hall

Results

- **Olney receiving dock (48x100) Lux at target**

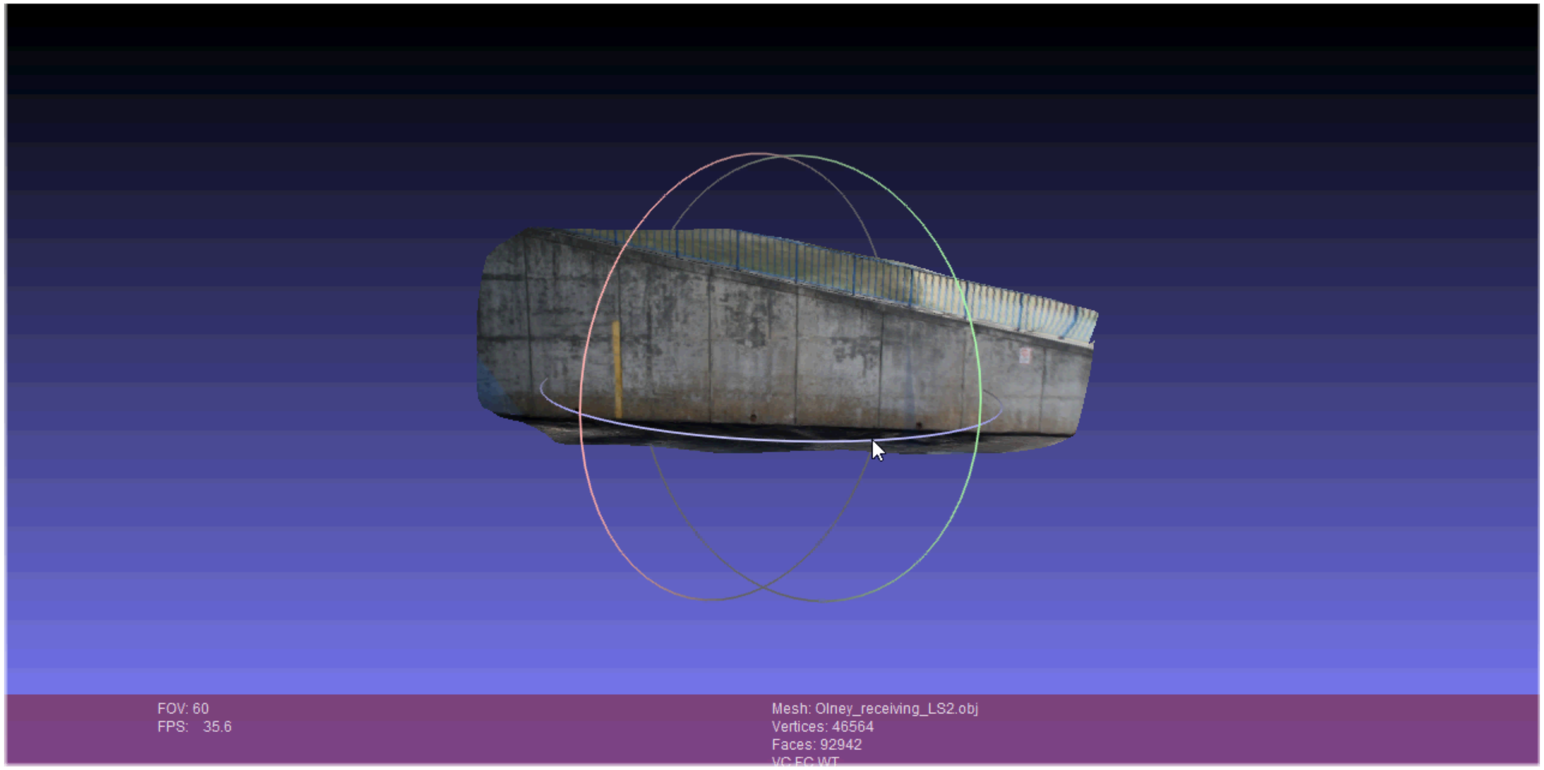


Fig 53: (left) &
Video 4: (above)
Olney receiving dock

Discussion and Summary

- **We now know it is possible to…**
  - Determine the location of a defect
  - Formulate the size
  - Apply to structural targets

- **The Goal now is to….**
  - Collect data about change in volume due to defects
  - Collect data for bridges in conjunction with the radar

Acknowledgments

Thank you to the Massachusetts Department of Transportation for their continued support of Umass Lowells S.E.R.G.

References

- Matthews, N. A. 2008. *Aerial and Close-Range Photogrammetric Technology: Providing Resource Documentation, Interpretation, and Preservation.* Technical Note 428. U.S. Department of the Interior, Bureau of Land Management, National Operations Center, Denver, Colorado. 42 pp
- H. Maas and U. Hampel, "Photogrammetric Techniques in Civil Engineering Material Testing and Structure Monitoring" Photogrammetric Engineering & Remote Sensing Vol. 72, No. 1, January 2006, pp. 000–000.
- A .Goshtasby *2-D and 3-D Image Registration For Medical, Remote Sensing, and Industrial Applications.* John Wiley & sons, Hobeken New Jersey 2005
- E. M. Mikhail, J. S Bethel, and J.C. McGlone, *Introduction to Modern Photogrammetry.* John Wiley and Sons, Hoboken New Jersey, 2001
- Sean P. Bemis, Steven Micklethwaite, Darren Turner, Mike R. James, Sinan Akciz, Sam T. Thiele, Hasnain Ali Bangash, Ground-based and UAV-Based photogrammetry: A multi-scale, high-resolution mapping tool for structural geology and paleoseismology, Journal of Structural Geology, Volume 69, Part A, December 2014, Pages 163-178, ISSN 0191-8141, http://dx.doi.org/10.1016/j.jsg.2014.10.007.
- Tang Z, Liang J, Guo C, Wang Y; Photogrammetry-based two-dimensional digital image correlation with nonperpendicular camera alignment. Opt. Eng. 0001;51(2):023602-1-023602-9. doi:10.1117/1.OE. 51.2.023602.
- P. Arias *, J. Armesto, H. Lorenzo, C. Ordóñez "DIGITAL PHOTOGRAMMETRY, GPR AND FINITE ELEMENTS IN HERITAGE DOCUMENTATION: GEOMETRY AND STRUCTURAL DAMAGES" ISPRS Commission V Symposium 'Image Engineering and Vision Metrology' Dep. Natural Resources Engineering and Environmental Engineering, University of Vigo, Campus Universitario As Lagoas – Marcosende s/n 36200 Vigo Spain – (parias, julia, hlorenzo, cgalan)@uvigo.es
- Aleix Cubells i Barceló "Structural assessment based on photogrammetry measurements and finite element method" Instituto Superior tecnico, Universidade de Lisboa.