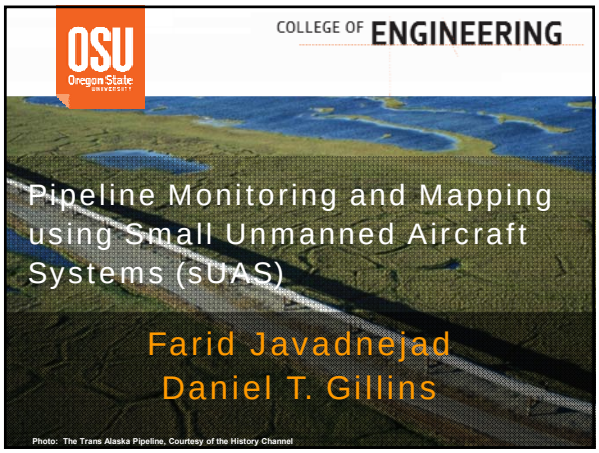
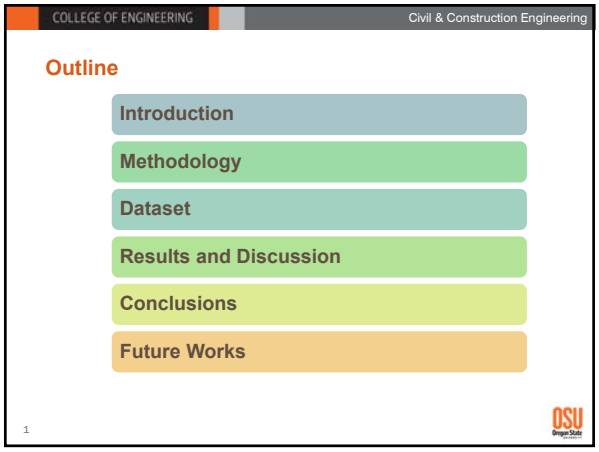

OSU
Oregon State
UNIVERSITY
COLLEGE OF ENGINEERING
Pipeline Monitoring and Mapping using Small Unmanned Aircraft Systems (sUAS)
Farid Javadnejad
Daniel T. Gillins
Photo: The Trans Alaska Pipeline, Courtesy of the History Channel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Civil & Construction Engineering
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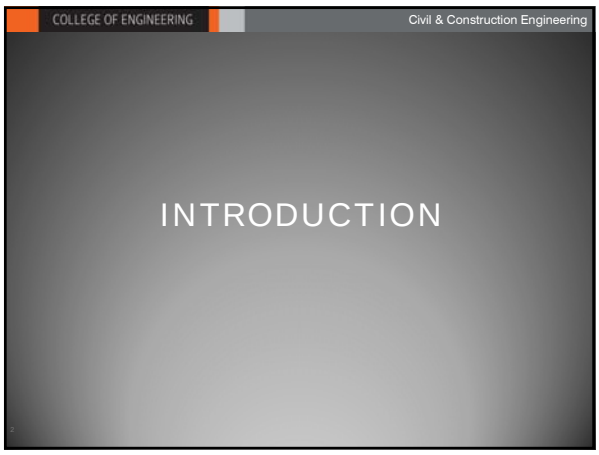
Introduction
Methodology
Dataset
Results and Discussion
Conclusions
Future Works
1
OSU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INTRODUCTION

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Applications of Pipelines

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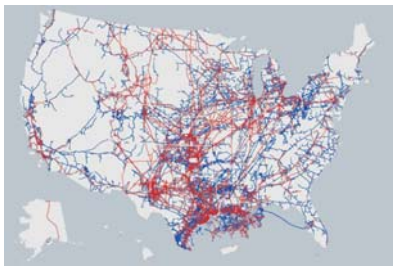
Gas & Oil Pipelines



Map of major natural gas and oil pipelines in the United States. Hazardous liquid lines in red, gas transmission lines in blue.

Source: Pipeline and Hazardous Materials Safety Administration.

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Hazards

The survival of the pipeline in the Denali Fault earthquake

- 7.9 Denali Fault earthquake in November 2002
- Trans-Alaska Oil Pipeline, built in the 1970's
- Value of oil flowing daily through the pipeline is about $25 million

Source: US Geological Survey Fact Sheet 014-03

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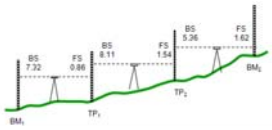
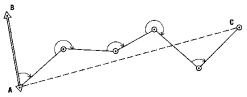
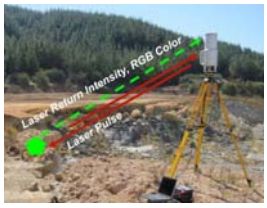
Monitoring



Differential Leveling



Transverse



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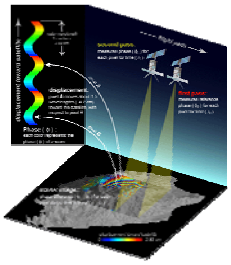
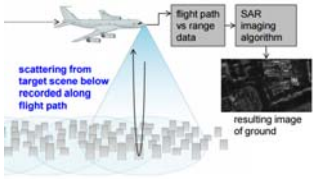
SAR & InSAR



Source: www.trussty.com



Benitz et al. (2011)

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Other Platform

Unmanned Aircraft Systems (UAS)

- Ease of use, low altitude maneuvering capabilities
- Low cost, time saving
- Inexpensive, consumer-grade sensors
- High resolution

METHODOLOGY

Unmanned Aircraft Systems (UAS)

Gillins et al. (2015)

Structure from Motion

- A computer vision technique
- For reconstructing 3D scenes
- From a series of overlapping images
- Inexpensive, consumer-grade cameras
- High-resolution mapping products

Snavely et al, 2006

Graphics: veprit.com

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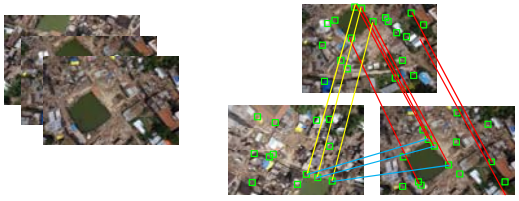
Structure from Motion



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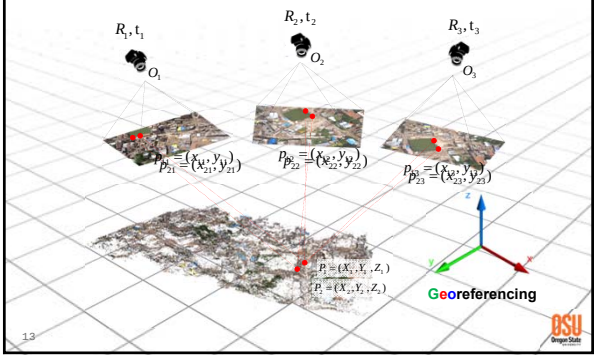
Structure from Motion



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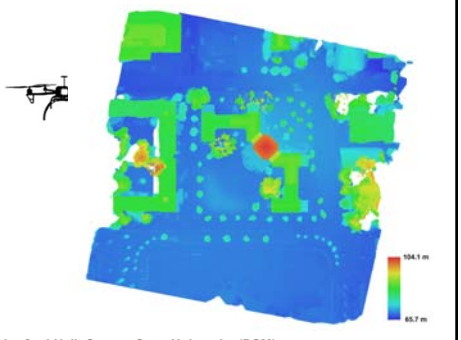

Weatherford Hall, Oregon State University (DSM)
Javadnejad et al, 2014

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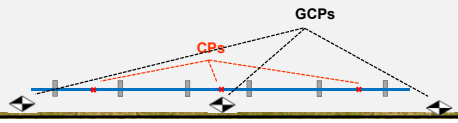
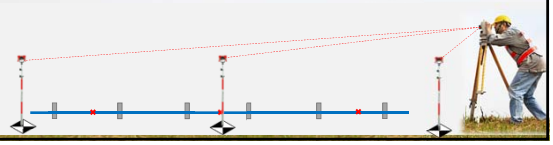
Weatherford Hall, Oregon State University (3D point cloud)

Javadnejad et al, 2014

Experiment Design



Experiment Design



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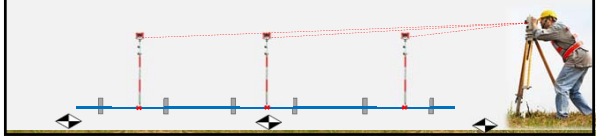
Experiment Design



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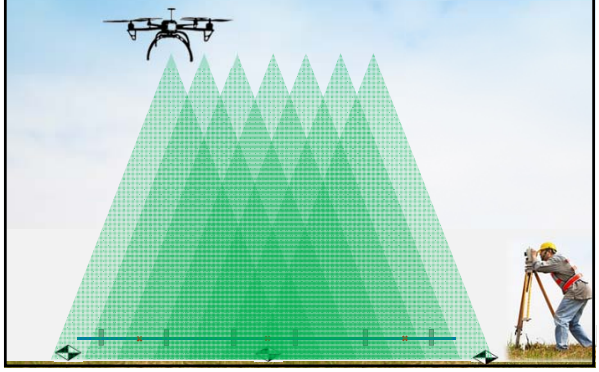
Experiment Design



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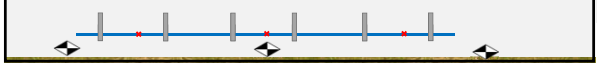
Experiment Design



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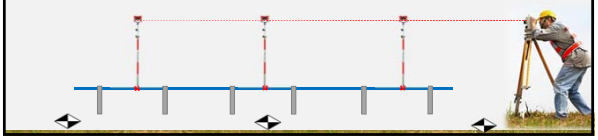
Experiment Design



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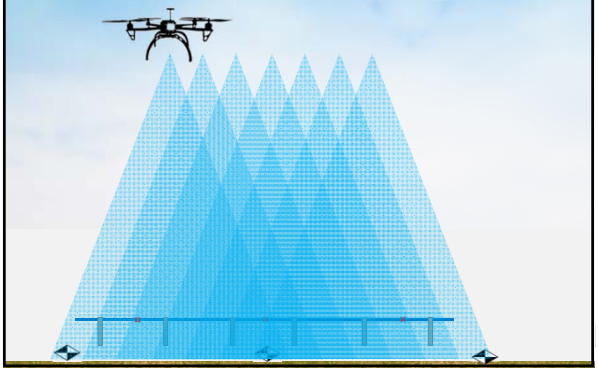
Experiment Design



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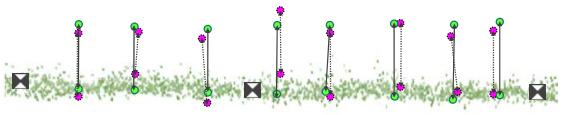
Accuracy Assessment



GCP used for georeferencing
Modeled CP position
Observed CP position
d_O = distance between ***observed*** CPs in *before* and *after* scenarios
d_M = distance between ***modeled*** CPs in *before* and *after* scenarios

$$\text{RMSD} = \sqrt{n^{-1}\sum_{i=1}^{n}(d_{M_i} - d_{O_i})^2}$$

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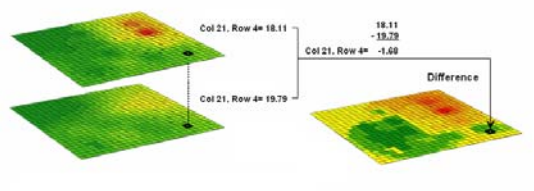
Change Detection

Spatial analysis in GIS



Map Algebra (Dana Tomlin, 1980)

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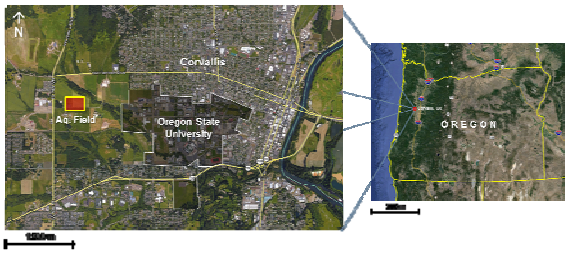
DATASET

- Site
- Equipment
- Survey

Site



Study Area on Oregon State University campus, Corvallis, OR

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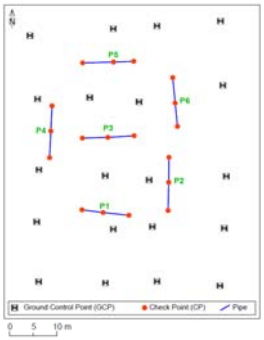
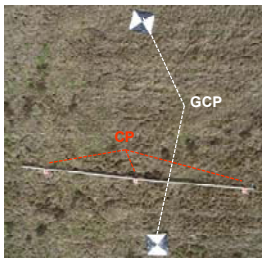
Site Setup





Number of GCPs = 20 - 1
Number of CPs = 18

GCPs & CPs

GCP surveyed with a Leica GS 14 GNSS receiver

Red tape on pipes used as CPs

Prism set on a CP while making measurements with a Leica TS 15 total station

Control Survey

GNSS Relative Positioning

Real Time Network (RTN)

- RTN Network: Oregon Real-time GNSS Network
- Receiver: Leica GS14
- Observations: 3-minute shots on each station
- Coordinate System: NAD83 State Plane Oregon North (2011) Geoid Model: Geoid 12A

Total Station Survey

Triangulation

- Equipment: Leica TPS15 1”
- Observations: 5 direct and 5 reverse shots on reflective prism

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Aerial Survey

Aeryon SkyRanger UAS platform

An example aerial image

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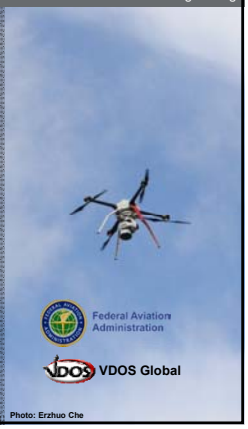
UAS Platfrom

Aeryon SkyRanger™
- Point-and-click touchscreen navigation
- Dynamic flight plans (AutoGrid™ mapping)

Photogrammetric Parameters
- Vertical photos
- Flight altitude: 45 m
- Forward overlap: 80%
- Side overlap: 80%

FAA Authorization
- The "Blanket" 200-foot COA
- Section 333 exemption
- Chief Pilot: Seth Johnson
- Date: 11/9/2015
- Start Time: 11:30 am
- End Time: 3:30 pm



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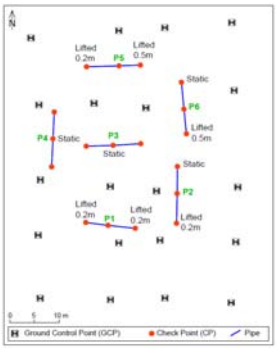
Change Scenario



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RESULTS AND DISCUSSION

- Least Squares Adjustment
- Structure-from-motion
- DEM of Difference
- Accuracy Analysis

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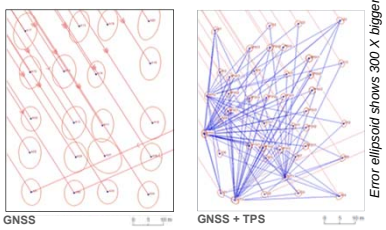
Least Squares Adjustment

Performed in MicroSurvey StarNet v8



Estimated accuracy of the control network (in meter)

Standard Deviation	Easting	Northing	Height	Horizontal
68% Confidence	±0.0014	±0.0017	±0.0016	±0.0022
95% Confidence	±0.0028	±0.0034	±0.0032	±0.0039

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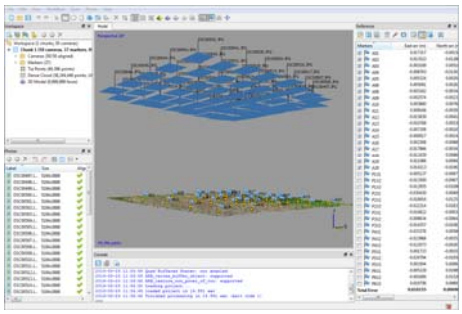
SfM Processing

Performed in AgiSoft PhotoScan 1.1



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Summary of SfM processing for *before* and *after* scenarios

	Before	After
# Images	50	50
Flight altitude (m)	48.5	45.5
Overlap		
Ground resolution (m/pixel)	0.012	0.011
Sparse cloud (pts)	49.9×10^3	49.8×10^3
Dense cloud (pts)	39.8×10^6	39.4×10^6
# GCPs	19	19
# CPs	18	15
GCP $RMSD_{3D}$ (m)	0.029 m	0.025 m
CP $RMSD_{3D}$ (m)	0.069 m	0.072 m

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Sparse Point Cloud

Scenario A (49.4k pts) Scenario B (49.8k pts)

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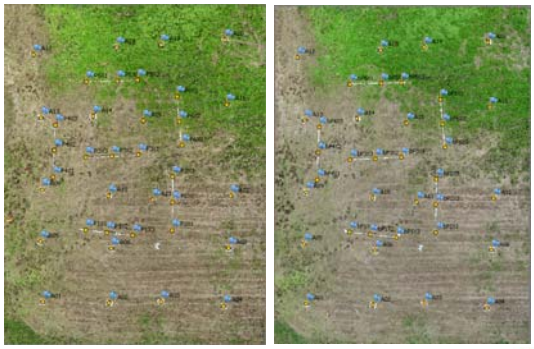
Dense Point Cloud



Scenario A (39.8M pts) Scenario B (39.4M pts)

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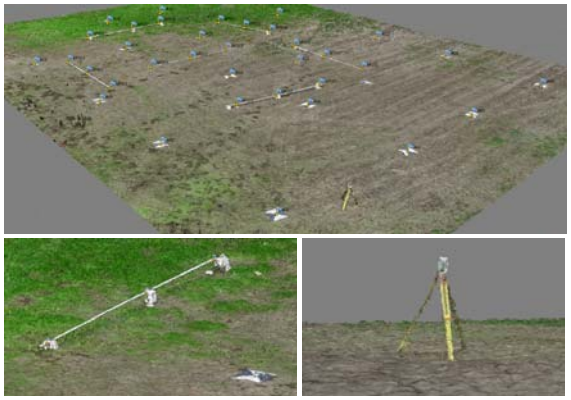
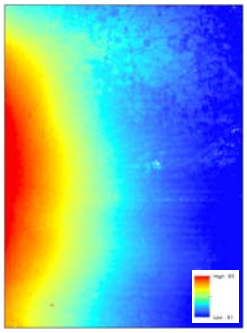
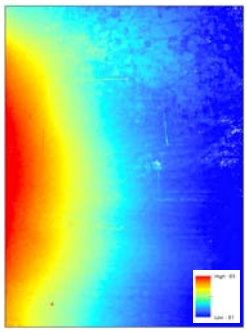


Digital Elevation Model (DEM)





Scenario A

Scenario B

Ground Resolution = 2.5 cm

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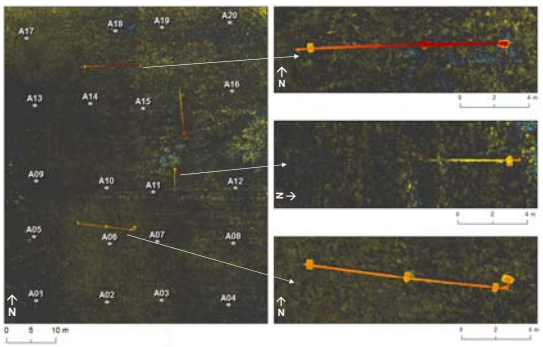
DoD



Vertical displacements as observed in survey network (dV_O) and as modeled in the DoD (dV_M) (values are in meters)

CP	dV_O	dV_M	Δ(dV)
$P1_{X1}$	0.210	0.221	0.011
$P1_{X2}$	0.183	0.196	0.013
$P1_{X3}$	0.248	0.242	-0.006
$P2_{X1}$	0.009	0.002	-0.007
$P2_{X2}$	0.017	0.020	0.003
$P2_{X3}$	0.193	0.204	0.011
$P3_{X1}$	0.009	0.006	-0.003
$P3_{X2}$	0.010	-0.006	-0.016
$P3_{X3}$	0.009	0.003	-0.006
$P4_{X1}$	0.007	0.004	-0.003
$P4_{X2}$	0.009	0.009	0.000
$P4_{X3}$	0.008	0.004	-0.004
$P5_{X1}$	0.242	0.242	0.000
$P5_{X2}$	0.389	0.412	0.023
$P5_{X3}$	0.479	0.493	0.014
		RMSD	0.010

CONCLUSIONS AND FUTURE WORKS

Conclusions

- A consumer-grade, non-calibrated camera was used
- UAS was tested as a platform
- A time series of imagery was collected inexpensively
- SfM was used to process images and generate DEMs
- DoD analysis was able to detect the vertical change of pipes
- Vertical change detection at cm-level
- $RMSD_V$ of 2 cm at 95% confidence
- Similar procedure for monitor ground movements

Future Works

- Identifying the error sources
- Studying the impact of spacing of the ground control points
- Impact of ground resolution
- Considering noise in point cloud
- Cloud-to-cloud comparison
- More case studies

Conducted by Geomatics Engineering Research group at Oregon State University

Acknowledgments

- Matthew Gillins
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VDOS Global

DAVID EVANS ASSOCIATES