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AOR Contact: Joshua Johnson and Zhongquan Zhou

An autonomous UAS inspection platform for high-efficiency 3D pipeline/route modeling/change-detection and gas leak detection-localization

PIs: Zhigang Shen, University of Nebraska-Lincoln

Acknowledgment

Researchers who had been working on this project

- Dr. Zhexiong Shang(UAS control and Path Planning Algorithm, 3D model pipeline database), Univ. Nebraska
- Dr. Chongsheng Cheng (thermal imaging experiments, testing platform setup, and lab tests), Univ. Nebraska
- Mr. Houman Kosarirad, Univ. Nebraska – Ph.D. Student

Pipeline Research Council International (PRCI) – TDC (Field Tests Support)

- Mr. Lance Abney
- Mr. Gary Hines

Agenda

1. Accomplishments
2. Problem Statement
3. Objectives
4. Tasks
5. Outcomes
6. Conclusions and Discussions

Accomplishments

Journal Papers

Google Scholar

	Title	Cited by	Year
1.	Topology-based UAV path planning for multi-view stereo 3D reconstruction of complex structures Z Shang, Z Shen Complex & Intelligent Systems 9 (1), 909-926	9	2023
2.	Flight Planning for Survey-Grade 3D Reconstruction of Truss Bridges Z Shang, Z Shen Remote Sensing 14 (14133200), https://doi.org/10.3390/rs14133200	8	2022

Conference poster /invited talk

1. Shang, Z., Shen, Z.,(2023) "Topology-based UAV path planning for automated multi-view stereo 3D reconstruction of complex structures" *Webinar to ASCE T&DI UAS Committee* on April 6
2. Shang, Z., Cheng, C., Clark, G., Shen, Z. (2020) "Detecting, locating, and mapping internal gas pipeline corrosion using thermography and photogrammetry" poster at the 2020 *PHMSA Pipeline R&D Forum,* February 19-20, Arlington, VA

Accomplishments

Supported Education

Undergraduate researcher

(1). Gabriel Clark, software engineering major, NASA and Microsoft intern, had been working on the project from September 2019 to July 2023. *Software Engineer at Microsoft*

PhDs

(1) Houman Kosarirad (current), PhD student at the University of Nebraska-Lincoln
(2) Chongsheng Cheng (2019-2020), *Associate Professor at Chongqing Jiaotong University*
(3) Zhexiong Shang (2019), *Associate Professor at Hainan University*

Postdoc fellows

(1) Chongsheng Cheng (2020), *Associate Professor, Chongqing Jiaotong University*
(2) Zhexiong Shang (2020-2022), *Associate Professor at Hainan University*

Problem Statement

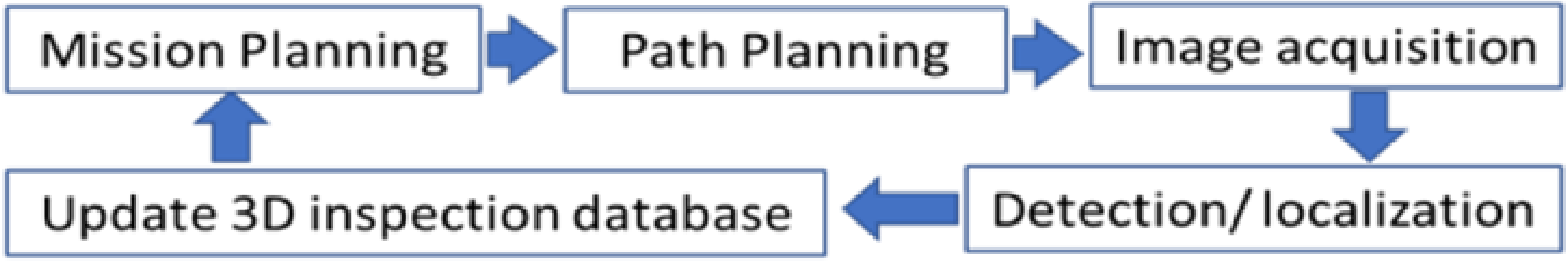
- Checking defects along 2.7M miles of gas pipeline and collecting timely inspection data is a daunting task despite the availability of modern UAS

- Challenges
  1. Inspection data collection (large quantity of high-quality 3D pipeline data)
  2. Inspection data management (how to reference the 3D defects data)

Problem Statement

The proposed solutions:

An end-to-end 3D data collection and management system



1. Inspection data collection (large quantity of high-quality 3D pipeline data)
   automate and enhance UAS inspection through 3D path planning
2. Inspection data management (how to reference the 3D defects data)
   3D model-based data management system with georeferencing capacity

Objectives

1. Develop a geo-referenced 3D data management system to manage the identified pipeline defect data
2. Develop 3D Coverage Path Planning algorithms to automate high-quality 3D pipeline inspection data collection
3. Develop a UAS-platform infrared-based gas leakage detection method to detect gas leakages along the pipelines

Major Tasks

Task 1: 3D inspection data management system

Task 2: 3D Coverage Path Planning Methods

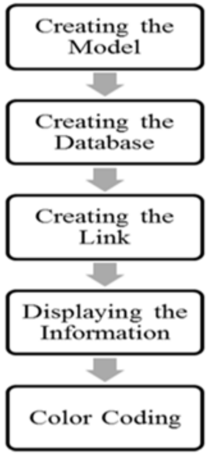
Task3: Develop or identify 3D profile change method

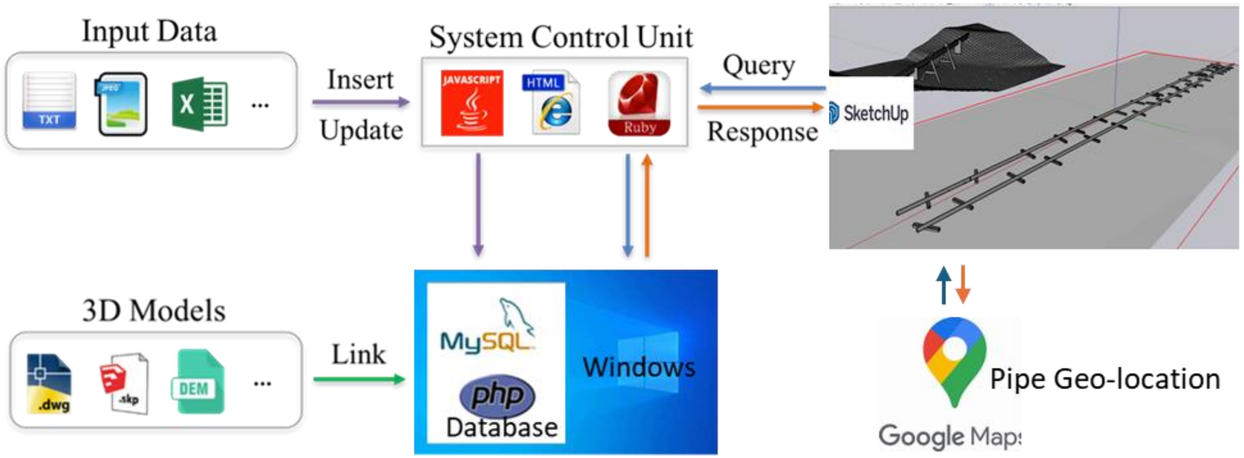
Task 4: Develop infrared-image-based gas leakage detection method

Task 5: Field validation

Outcomes

- **Task 1: 3D data management system**

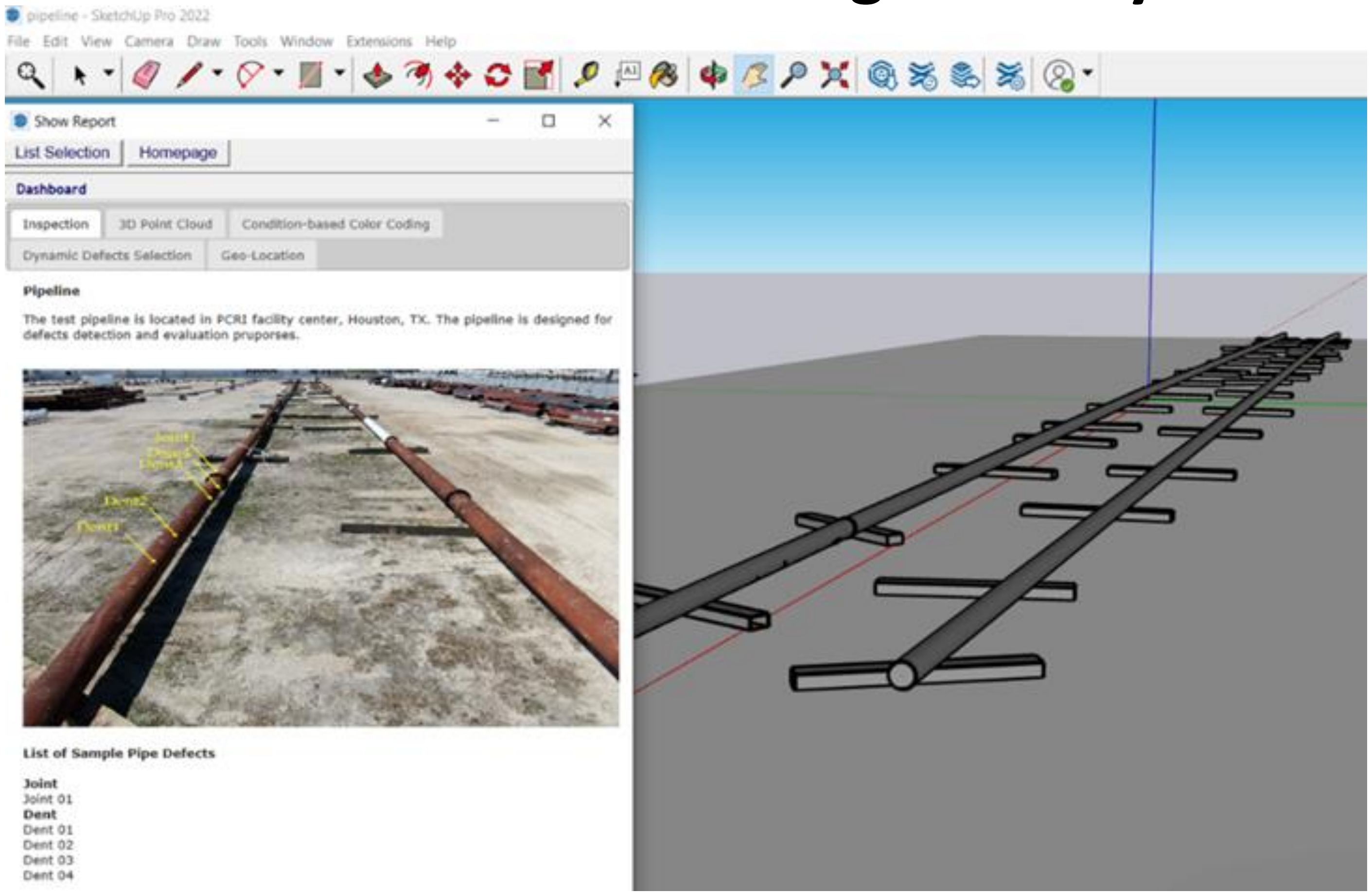


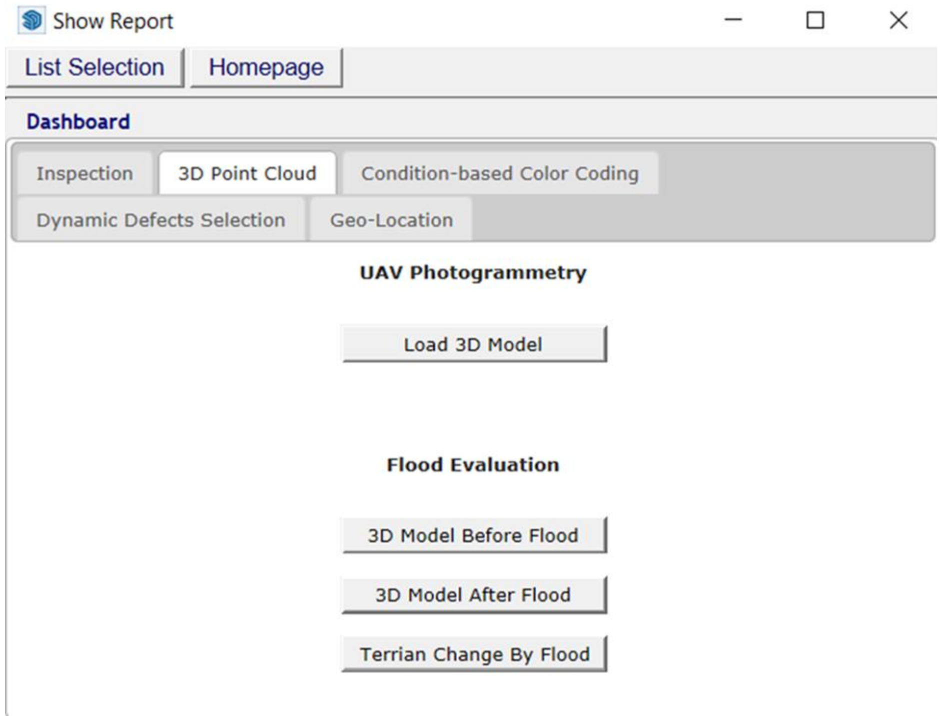


System Overview

Outcomes

- Task 1: 3D data management system

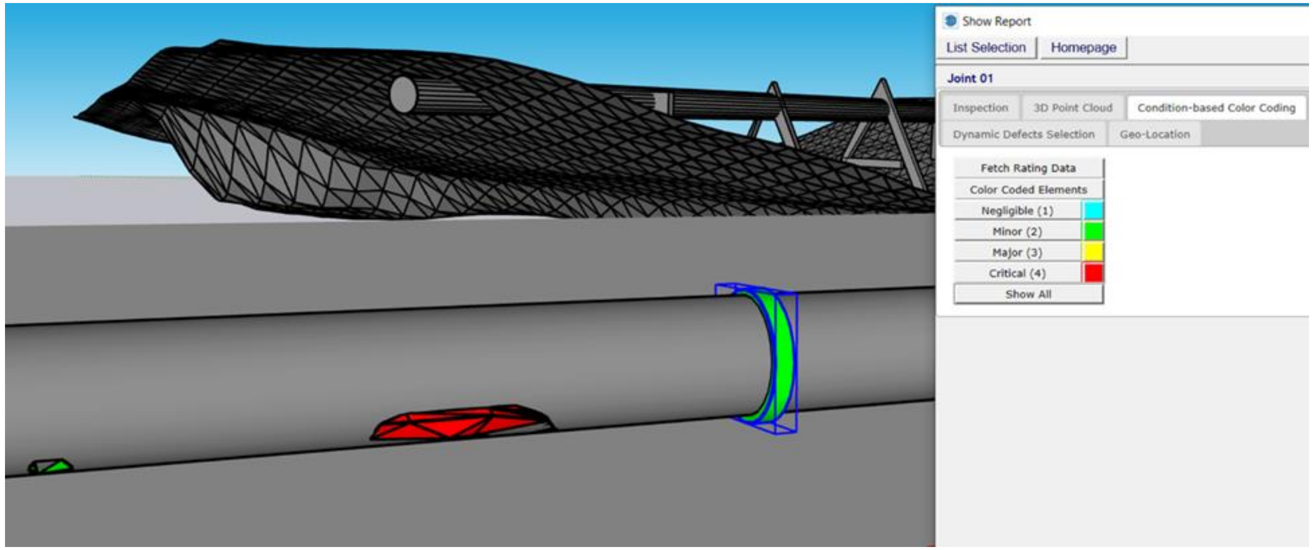


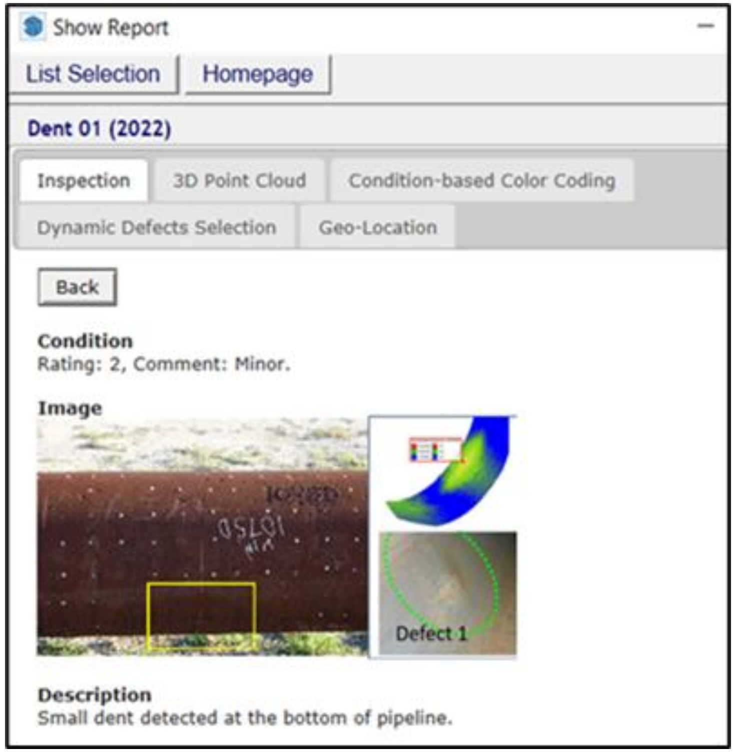


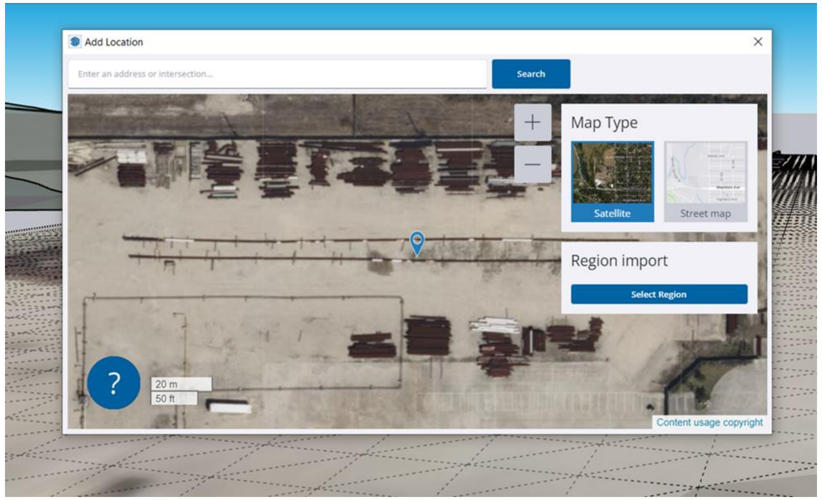
Implemented Demonstration System

Outcomes

- Task 1: 3D data management system





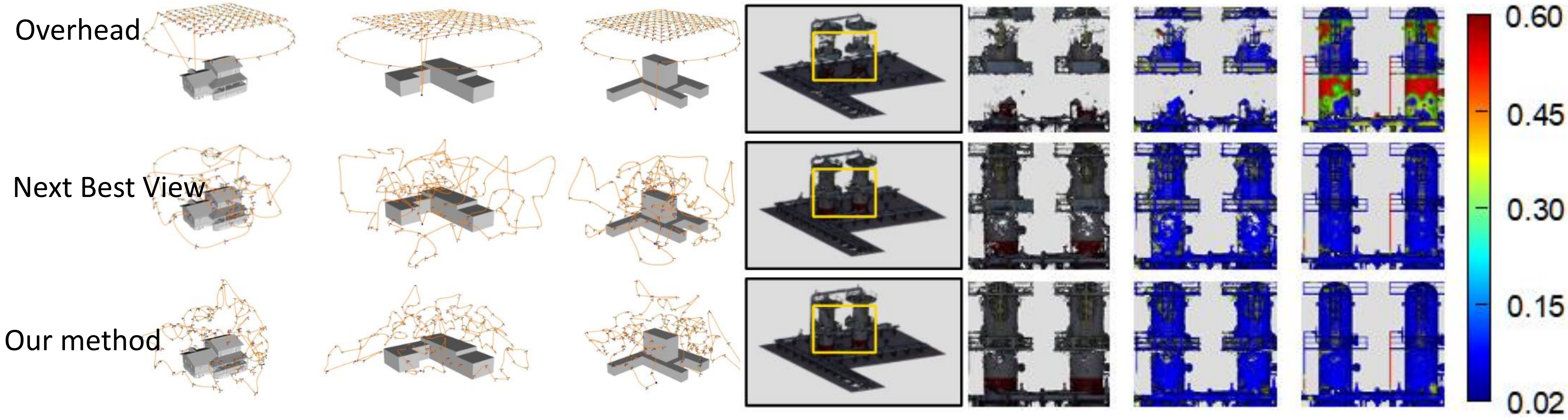


Case Examples

Field Pipelines

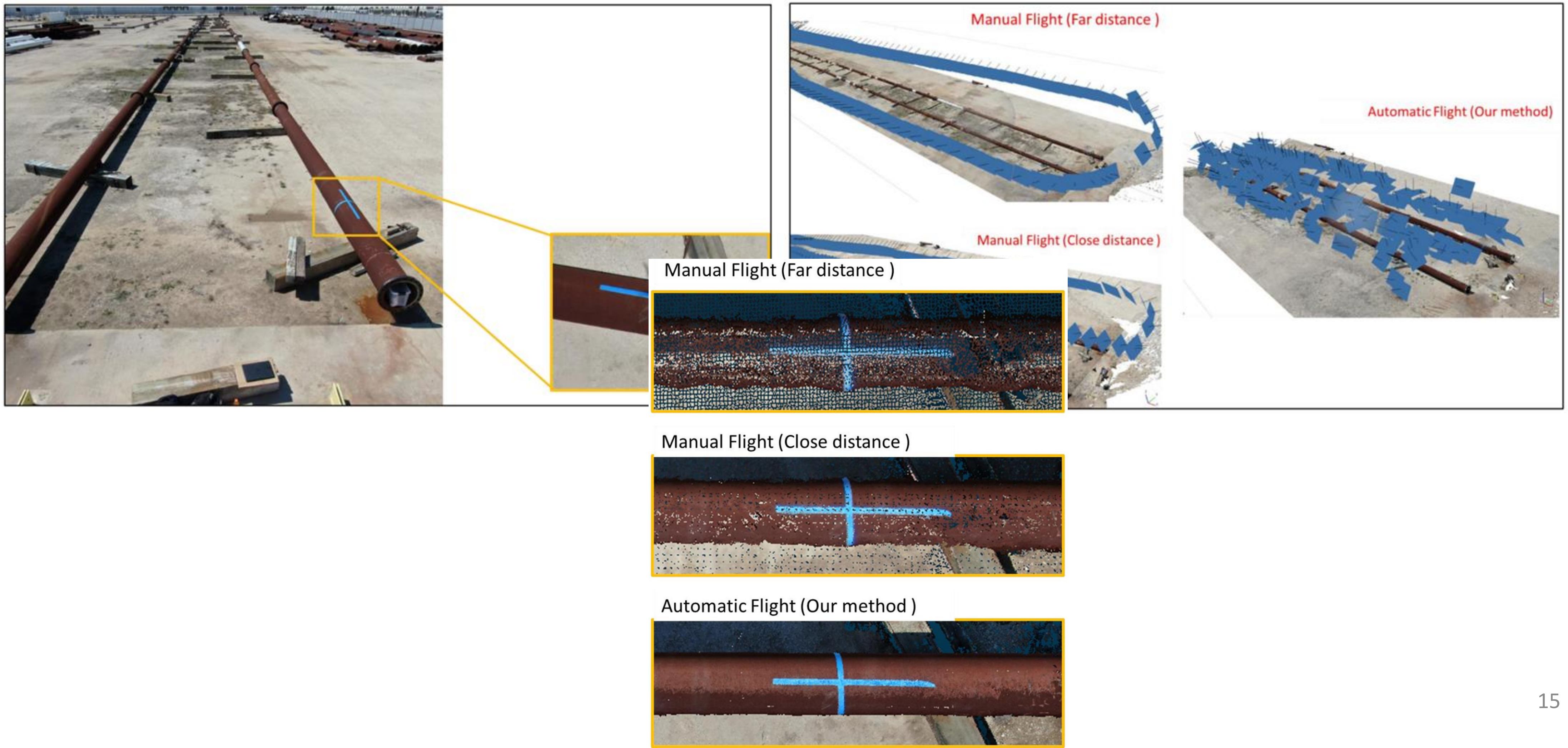
Outcomes

- **Task 2: Quality-based 3D CPP**



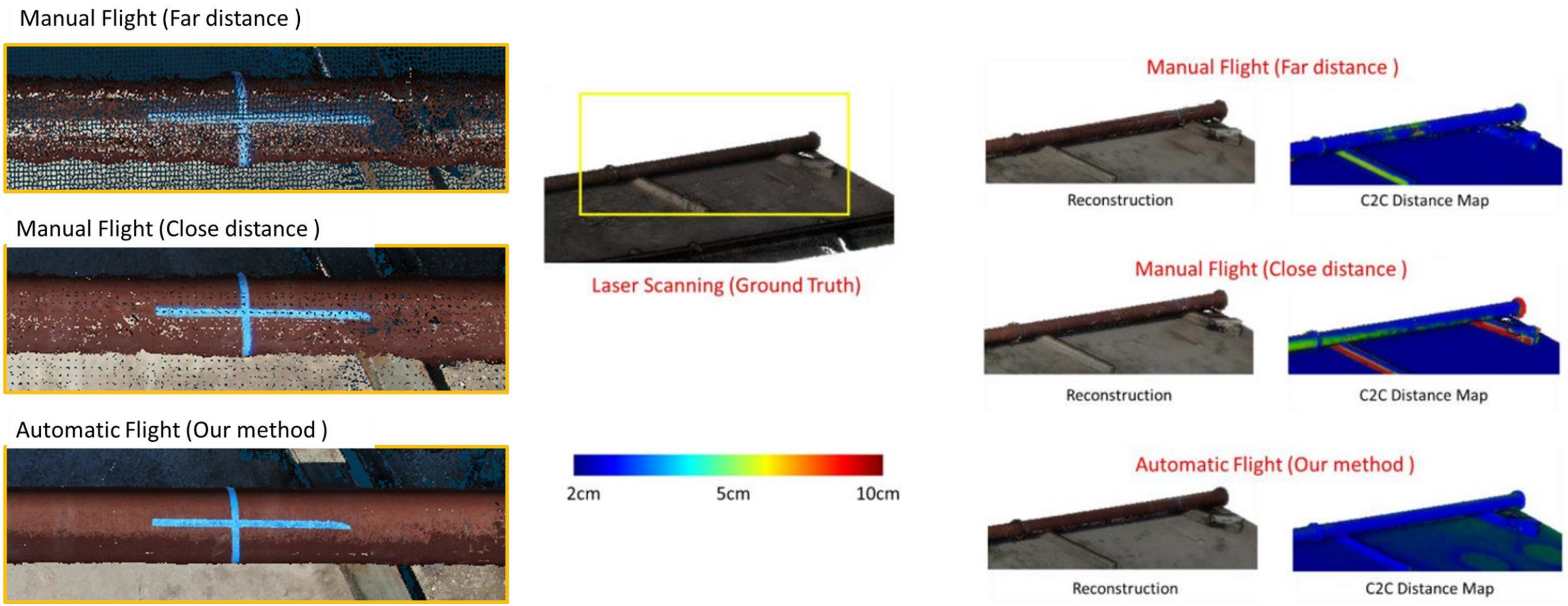
Outcomes

- **Task 2: Quality-based 3D CPP-Field Test**



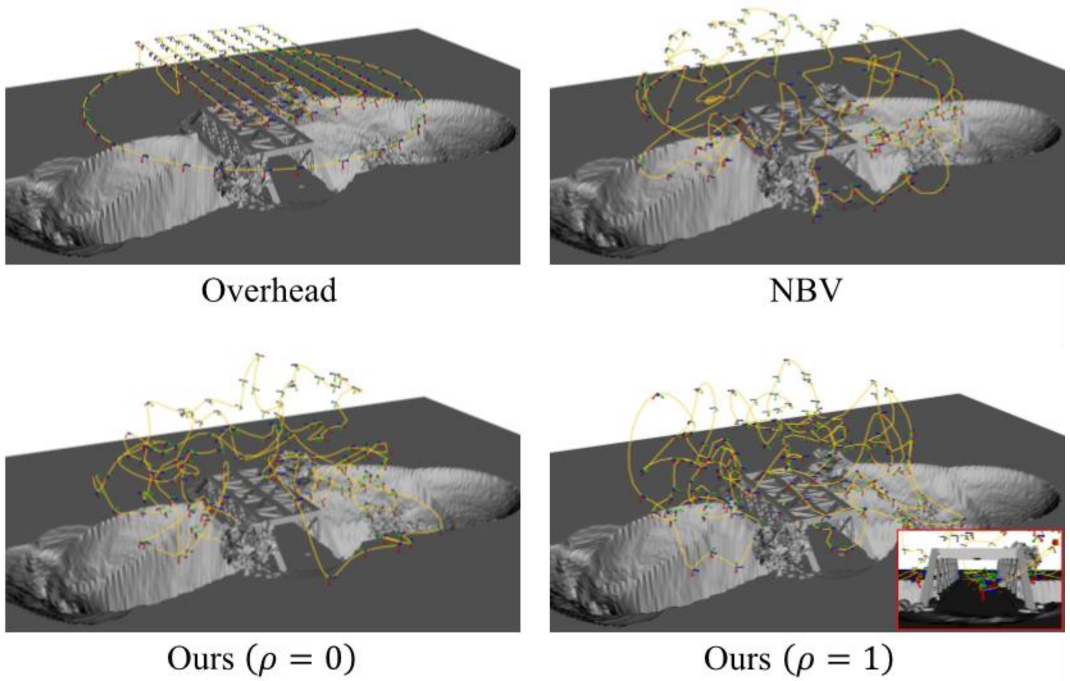
Outcomes

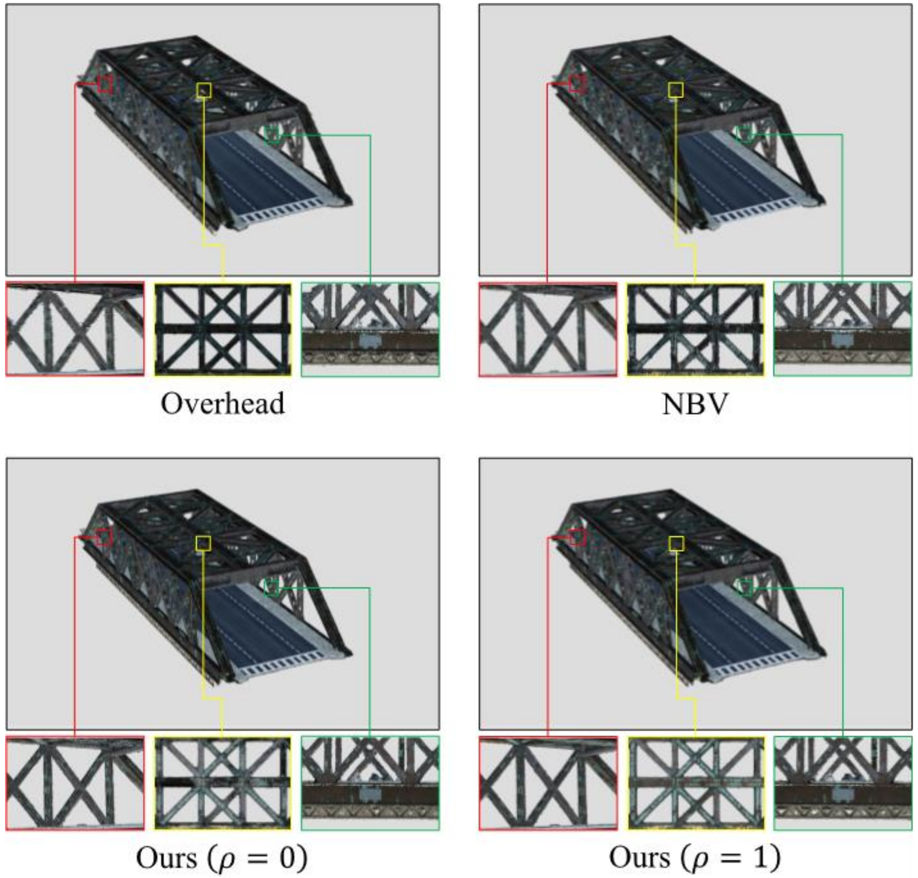
- **Task 2: Quality-based 3D CPP-Field Test**



Outcomes

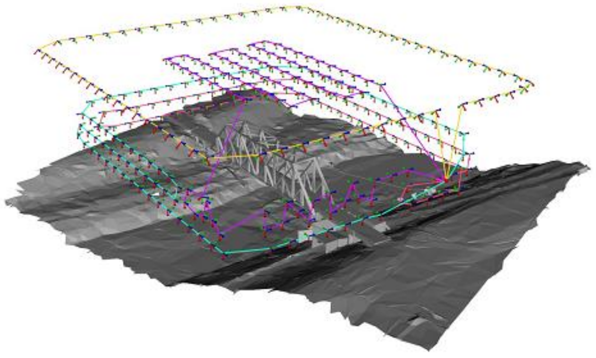
- **Task 2: Truss-structure**



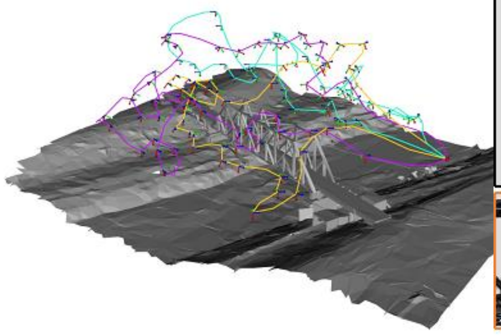


Outcomes

- **Task 2: Truss-structure-field test**



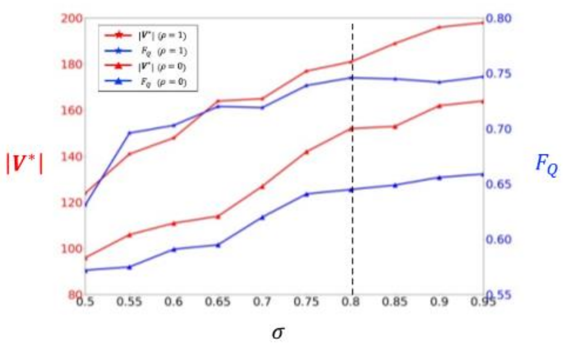
Zheng et al. (2018)



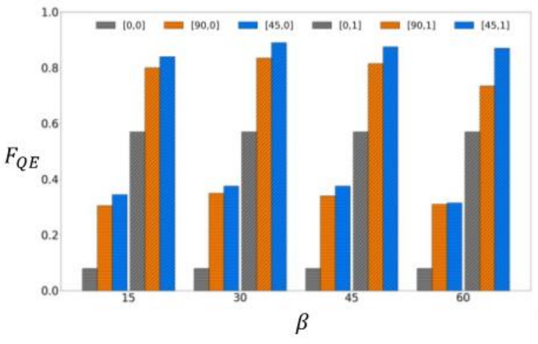
Ours

TLS | Zheng et al. (2018) Routes 1&3 | Zheng et al. (2018) | Ours

Method	F-Score ($\mathcal{P}, \mathcal{R}$) $\chi = 0.05$	$\chi = 0.1$	$\chi = 0.2$
Zheng et al. [14] (Route1&3)	45.21 (35.66, 61.75)	55.89 (41.44, 85.81)	64.87 (48.90, 96.31)
Zheng et al. [14] (Routes 1&2&3)	56.07 (**43.41**, 79.14)	63.89 (49.12, 91.37)	71.23 (56.12, 97.47)
Ours ($\rho = 0$)	**56.31** (41.33, **80.41**)	**64.55** (**49.83**, **91.61**)	**71.79** (**56.75**, **97.70**)



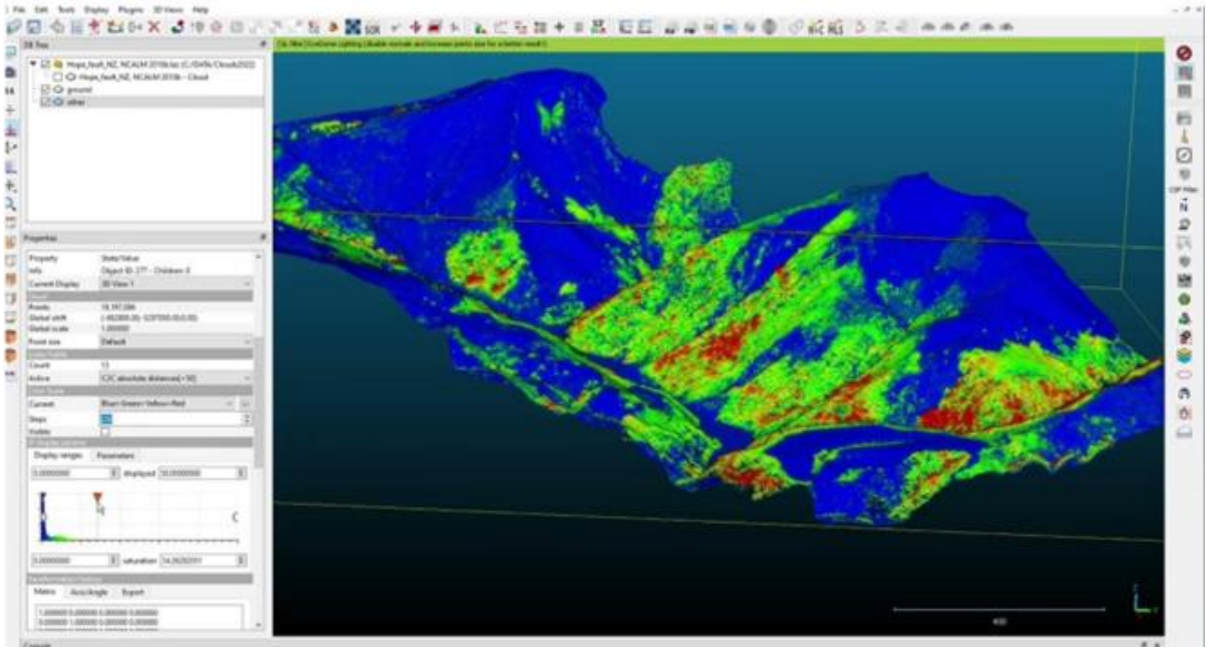
(a)



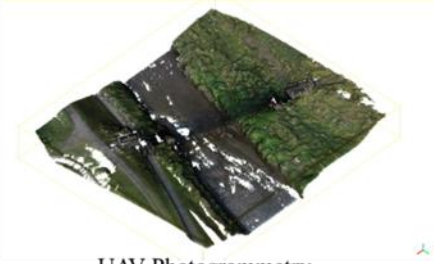
(b)

Outcomes

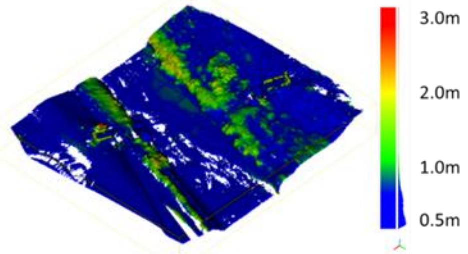
- **Task 3: Identify 3D Profile Change: CloudCompare**



Site Model from Google Map



UAV Photogrammetry
(Taken on May 2022)

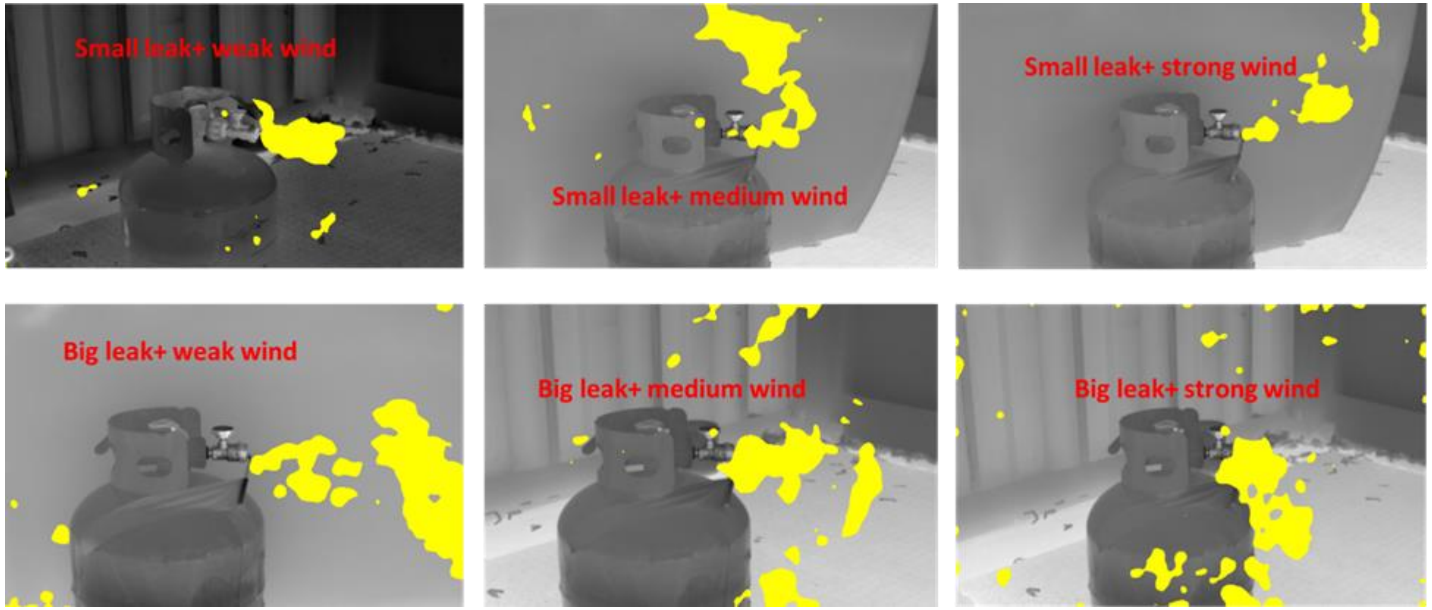


Site Changes between Satellite Images and UAV Photogrammetry

Comments:
It seems most of the changes on site are caused by the 1-3 meters growth of the trees/grasses on both sides of the river between the time spans of the two scans

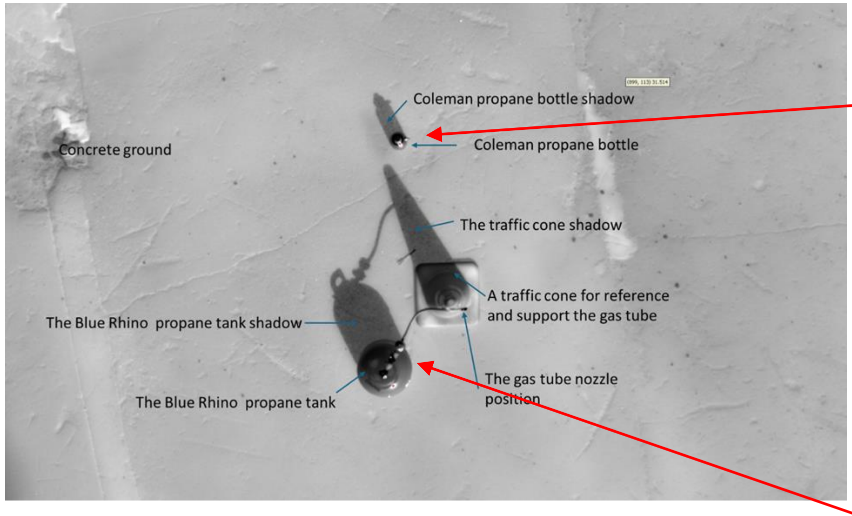
Outcomes

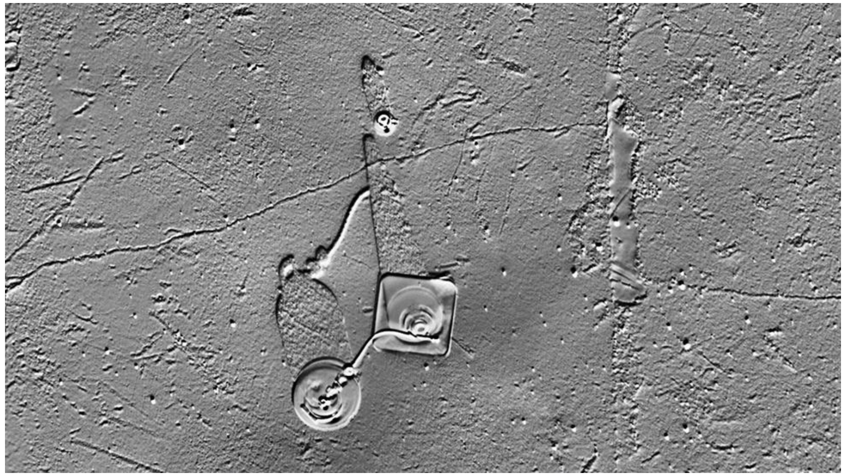
- Task 4: Infrared-image-based gas leakage detection

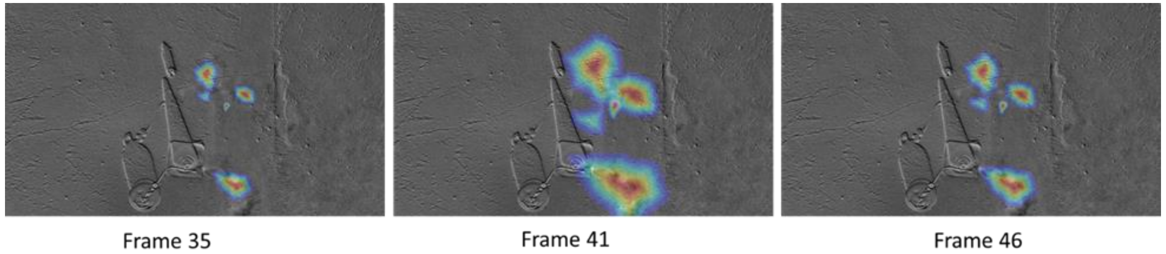


Outcomes

- **Task 4: Infrared-image-based gas leakage detection-Field Test**







Processed Image –Time Series

Conclusions

1. The performance of the 3D CPP accuracy is comparable to the traditional laser scanning method but takes much less time compared to the time-consuming stationary terrestrial laser scanning methods. And thus, it allows UAS to be widely used as an automated powerful gas pipeline inspection tool.

2. The proposed data acquisition system (UAS and 3D CCP) and the proposed infrared image processing method working together can be used to detect pipeline gas leakage.

3. The 3D inspection data can be managed more visually using 3D geo-referenced 3D models to allow more accurate documentation of the defects' locations.

Discussions

Concerning API 653, since the developed inspection method is based on the accuracy of the reconstructed 3D models with texture, it can be used to conduct tank settlement evaluations, such as factors of out-of-plane, body-tilting, edge settlement, and other body deformations when the body changes of geometry dimensions greater than 2 centimeters.

Concerning Right of Way Encroachment, based on the field test result of the truss-bridge case, encroachment or river scour sediment or soil movement can be detected if the distance (change) value is greater than 5 centimeters.

Project Page & Final Reporting

More detailed information and the final report is available on the project page

https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=844

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