New Tools for Automating Arcjet Sample Recession Tracking and Analysis

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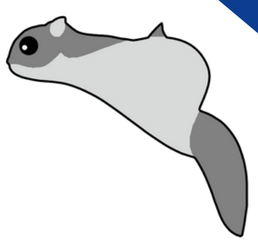

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1. Introduction

- NASA heatshields **require** extensive ground testing and modeling.

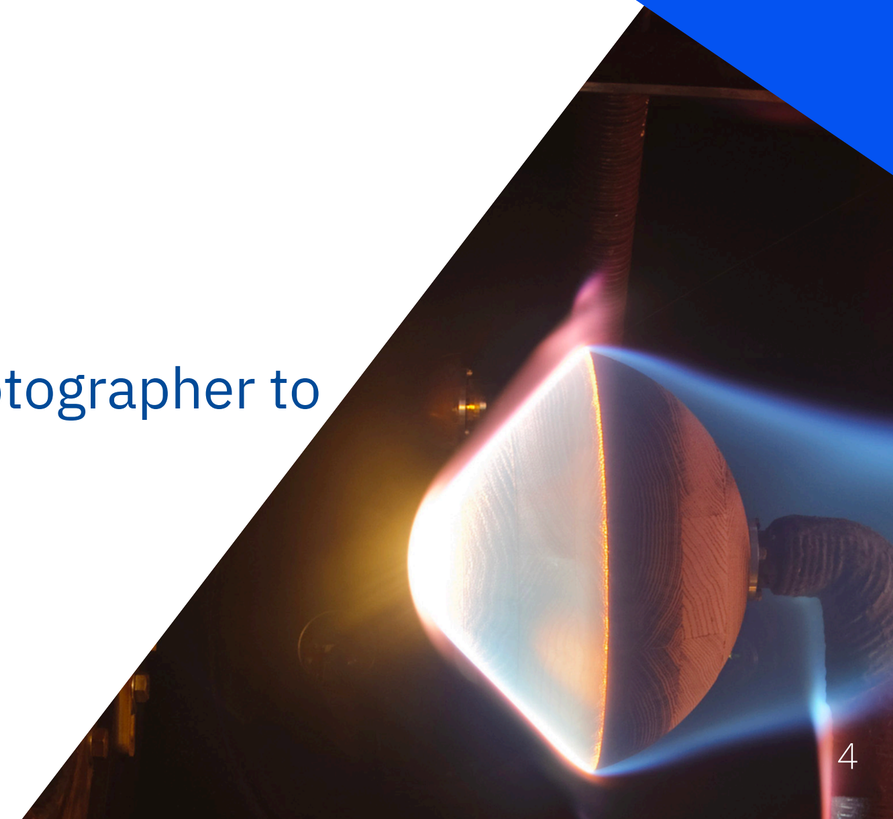
- Ground tests are **expensive** and complex but necessary to evaluate material performance.

→ **Maximizing Data** Extraction in Each Arcjet Test is important !

2. Motivation

Current capabilities:

- **arcjetCV:**
  - Automated recession analysis from video.
  - 2D model validation.
  - Time resolved validation.
- **Manual Photography**
  - 4 views per model, requires lead time for facility photographer to process.
- **Laser scanner:**
  - Pre/post test 3D scans (10 minutes/model).



2. Motivation

Goals:

- **arcjetCV improvement:**
  - Improve machine learning model for recession tracking from videos.
  - Simplify software distribution.

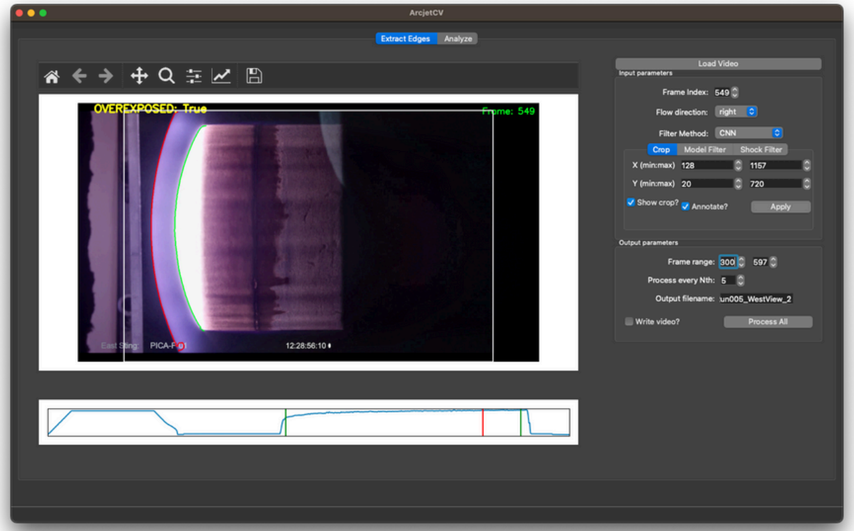
- **STARscan development:**
  - Automate 3D reconstruction, imaging, alignment and analysis scanner.
  - Eliminate pretest imaging and 3D scanning bottleneck.

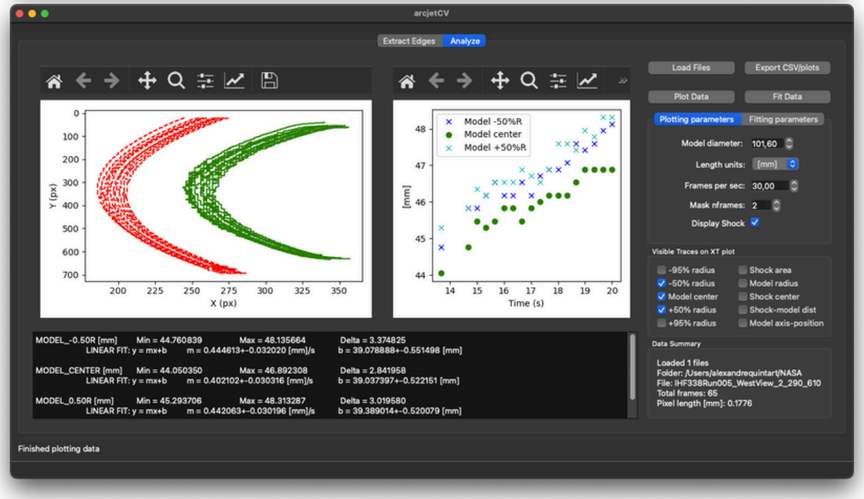
Recession from videos

arcjetCV

Ablation analysis during test

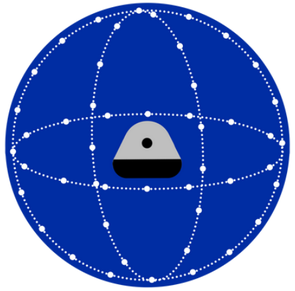
- **open-source software** tool for analyzing heatshield material performance during arcjet tests.
- **Machine learning** (CNN) models for automated video segmentation.
- Tracks **time-dependent** material **recession** and shock standoff distance.
- GUI for **user-friendly** operation; API for batch processing.



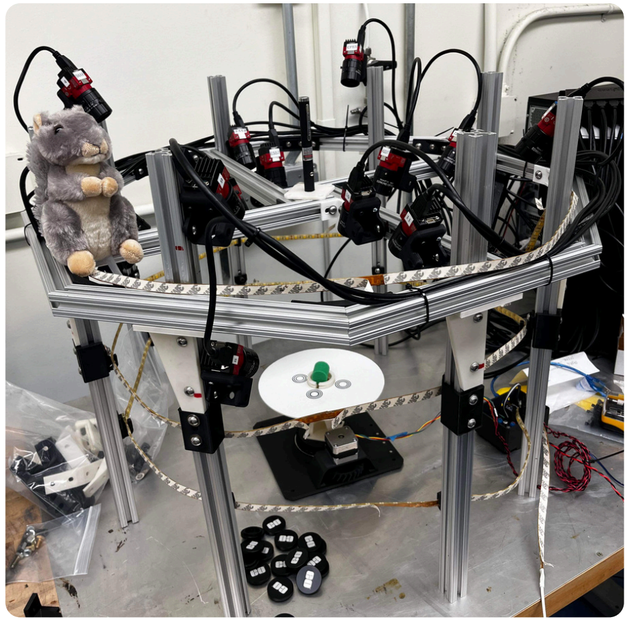


New photogrammetry scanner

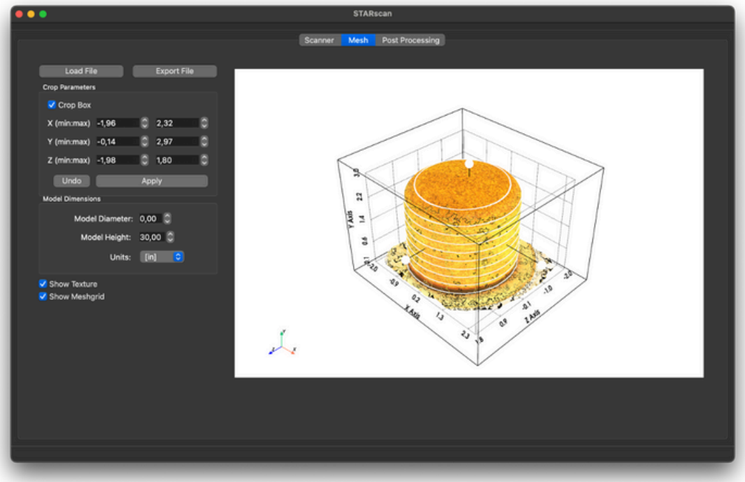
STARscan



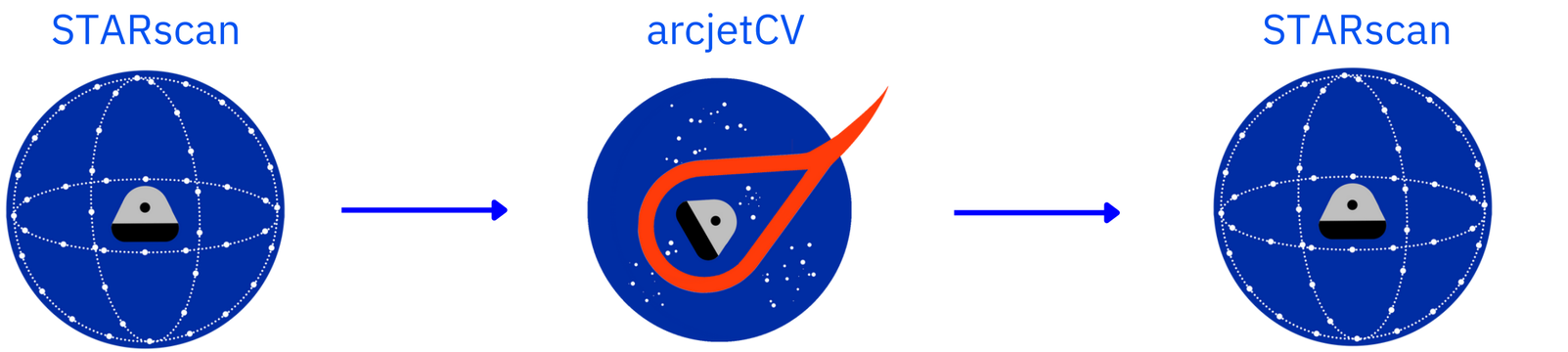
Scan sample before and after test



- 2 custom **3D scanning systems** built to accelerate and streamline scanning and analysis of arcjet test articles.
- **Software** that provides analysis of the shoulder **curvature**, **roughness** and **recession**.
- **Principle:** Photogrammetry
- **Accuracy:** ~ 0.35mm
- **Scan time:** 2 min



New Arcjet Test Analysis Process



Benefits:

- Cross-validation.
- In house 3D analysis pipeline.
- Standard imaging of models.
- Faster analysis and scanning.

arcjetCV improvement

Goals

- Increase the accuracy of the convolutional neural network detection.
- Make it easier to distribute the software around.

Improvements:

- New edge class
- New architecture
- Expanded training dataset
- Distribution on pypi (Python Package Index)
- Available as an executable for Windows (.exe) and macOS (.app)
- Distribution on conda

arcjetCV: Edge class

Problem:

- Standard CNN architectures may **struggle** with accurate **edge detection** in samples where boundary details are critical.
- Misclassification or blurring of edge regions can lead to **errors** in measuring **recession**.

Solution:

- Introduce a **dedicated class** for sample edges.

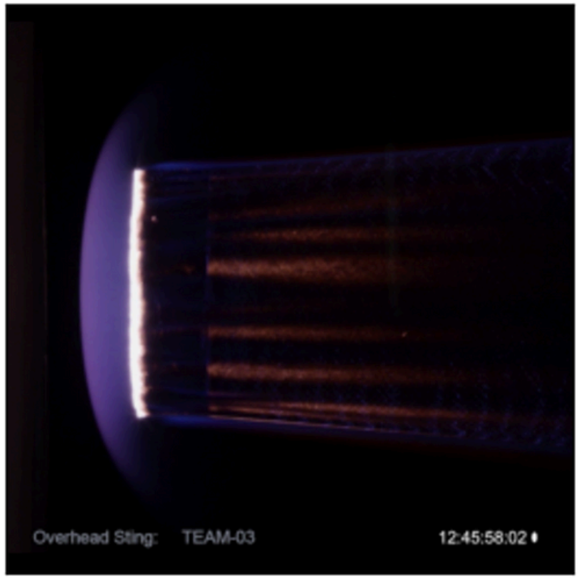
→ This class specifically labels boundary areas where material recession occurs, allowing the model to **focus** on fine **edge** details.

Advantages:

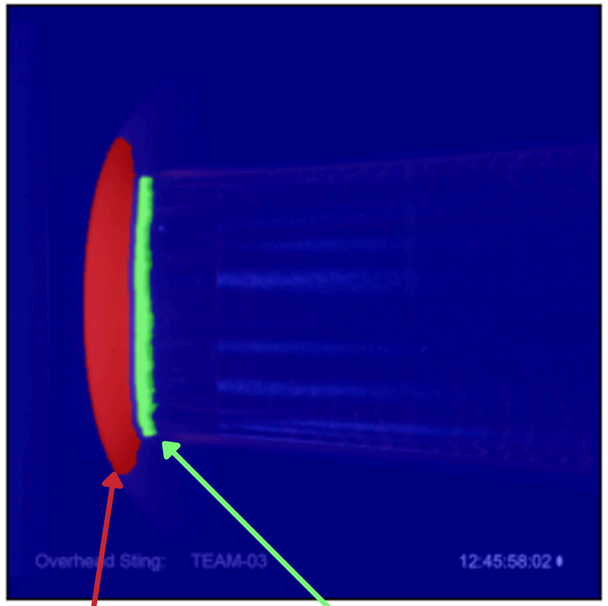
- **Reduced misclassification**:by distinguishing edge from non-edge pixels more effectively, minimizing errors in recession measurement.”

arcjetCV: Edge class

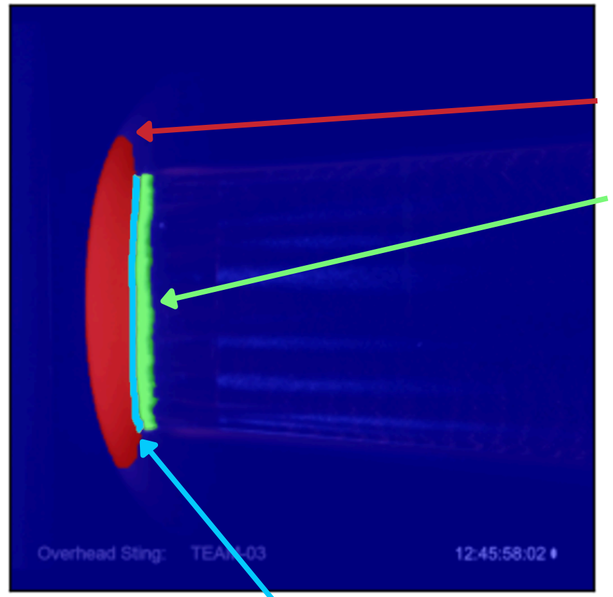
Original frame



Old training mask



New training mask



arcjetCV: New architecture

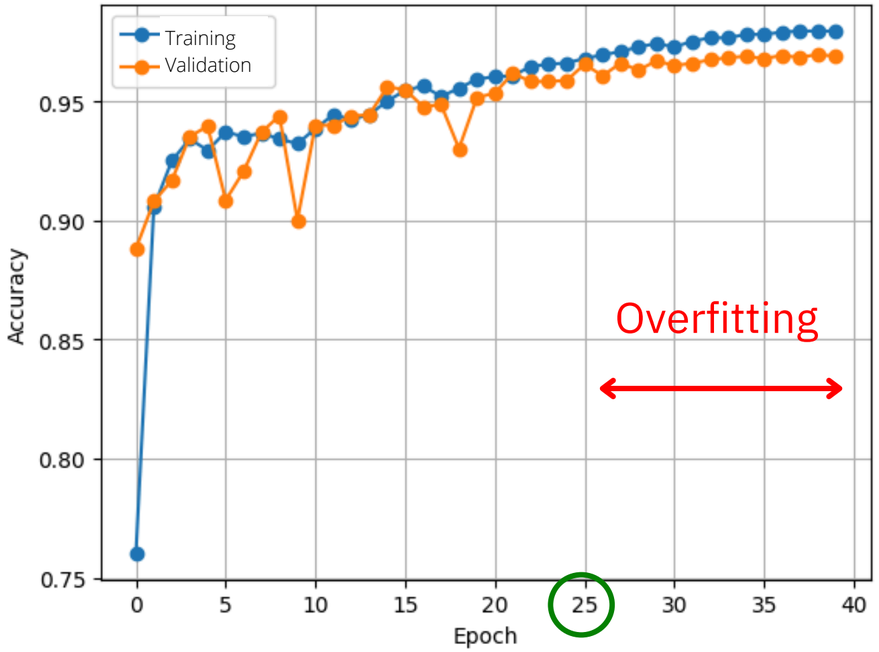
Xception

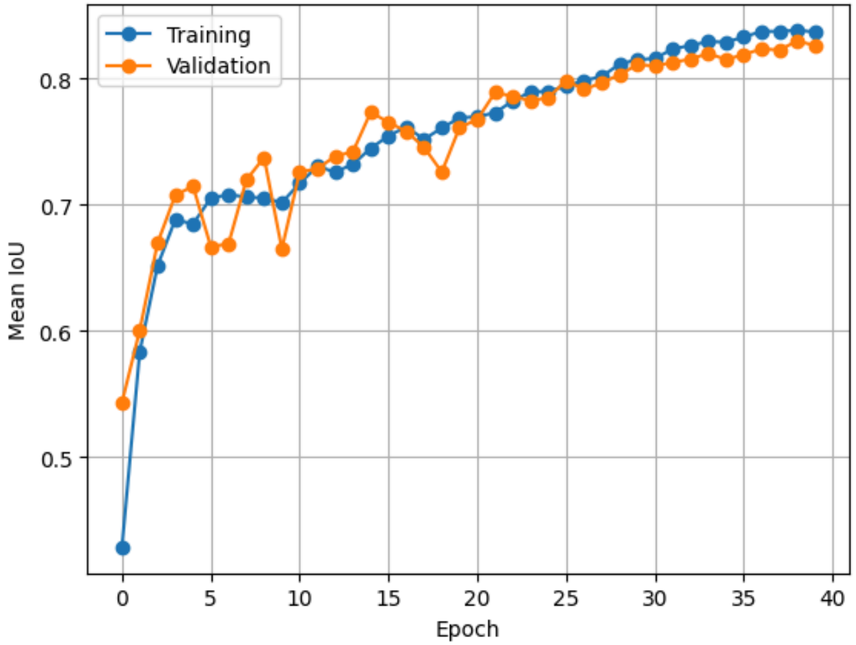
Key Advantages:

- **Improved Edge Detection:** Xception captures fine details, making it ideal for tasks needing precise segmentation.
- **Superior Feature Extraction:** Residual connections in Xception improve feature learning over VGG16’s standard convolutions.
- **Higher Accuracy & Lower Cost:** Xception delivers better accuracy and is computationally more efficient, despite its deeper architecture.

Conclusion: Xception is a more effective model for high-precision tasks like edge segmentation.

ML architecture performance





Model with 25 epochs	Pixel Accuracy	mIoU
VGG16 (Old model)	0.9411	0.7311
ResNet18	0.9413	0.7543
Xception	**0.9687**	**0.8005**

$$\text{Pixel Accuracy} = \frac{\text{Number of Correctly Classified Pixels}}{\text{Total Number of Pixels}}$$

Mean Intersection over Union (mIoU):

$$\text{mIoU} = \frac{1}{N}\sum_{i=1}^{N}\text{IoU}_i$$

$$\text{IoU}_i = \frac{\text{TP}_i}{\text{TP}_i + \text{FP}_i + \text{FN}_i}$$

→Handles Class Imbalance

where N = Total number of classes.

where:

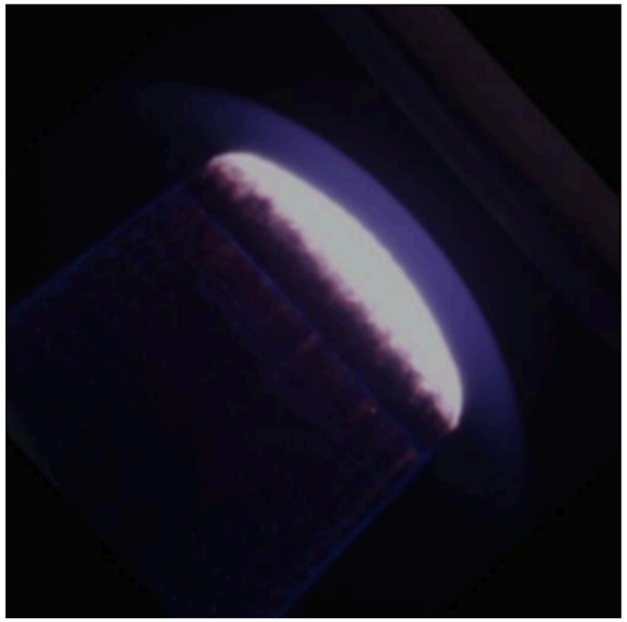
- True Positive (TP) = Pixels correctly predicted for class i,
- False Positive (FP) = Pixels incorrectly predicted as class i,
- False Negative (FN) = Pixels of class i that were missed.

arcjetCV: Augmented training dataset

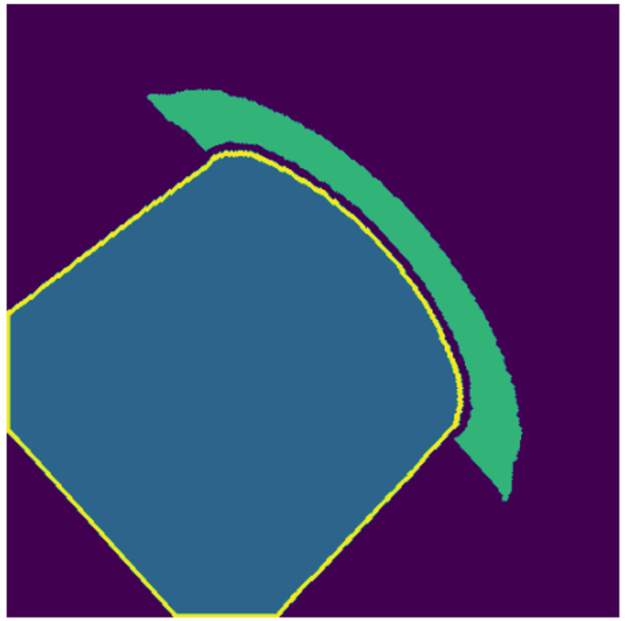
- New frames from different facilities.
    - VKI
    - UIUC
- New frames from new tests.

→ Size of the new dataset: **1778** training frames.

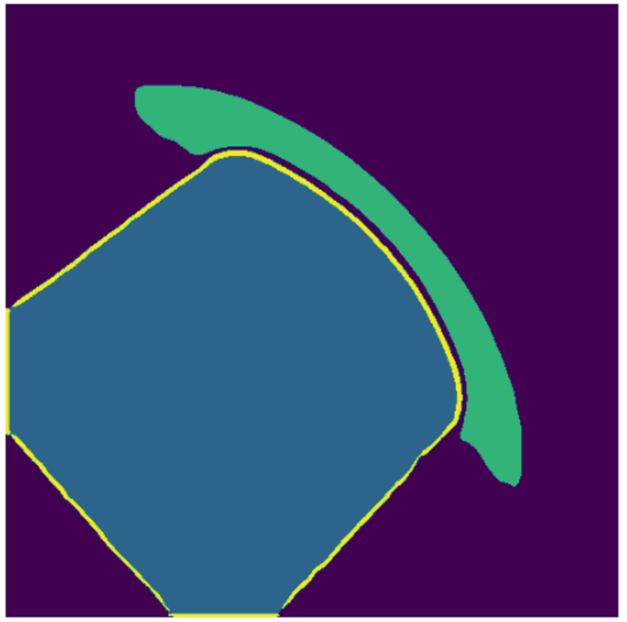
arcjetCV: New model result



Challenging video frame



Ground truth masks



Xception prediction

Recomended

arcjetCV: Pypi installation

1) Open your terminal

2) Install arcjetCV

```
pip install arcjetCV
```

3) Run arcjetCV:

```
arcjetCV
```

Easiest BUT Slower

arcjetCV: Executable installation

Download the excecutable .exe or .app here:

Flexible

arcjetCV: conda installation

1) Open your terminal

2) Install arcjetCV

Prerequisites:

- git-lfs
- Miniconda or Anaconda
- Xcode Command Line Tools (macOS only)

Windows Users and Developers

```
git clone https://github.com/magnus-haw/arcjetCV.git
cd arcjetCV
conda env create -f env/arcjetCV_env_[cpu/gpu].yml
conda activate arcjetCV
python -m pip install -e .
```

Unix Users (macOS and Linux)

```
conda create --name arcjetcv conda-forge::arcjetcv
```

3) Run arcjetCV:

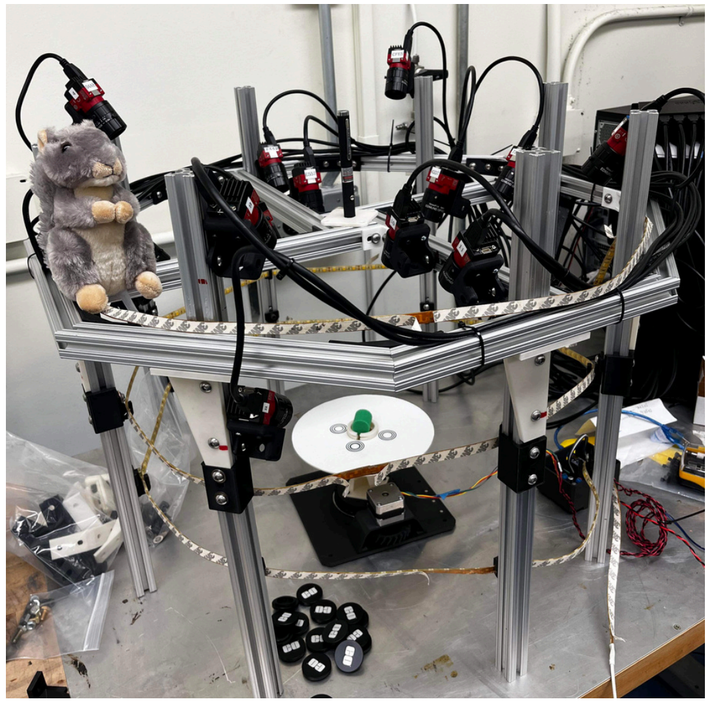
```
conda activate arcjetCV
arcjetCV
```

see the Git Repo

STARscan Scanners

Static Config (16+ cameras)

- Expensive (more cameras)
- Not portable
- Longer calibration
+ Faster scan



Turntable Config (6 cameras)

+ Cheaper (fewer cameras)
+ Portable
+ Fast to calibrate
- Longer to scan

STARscan Scanners Hardware

- **Cameras:**

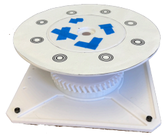
AlliedVision 12MP, VimbaX API, 16mm f/1.6 lens, Min iris: ~F13

- **Rig:**

8020 bars & 3D connectors, flexible T-nut mounts

- **CCTags:**

Circular patterns for scaling and alignment



- **Turntable:**

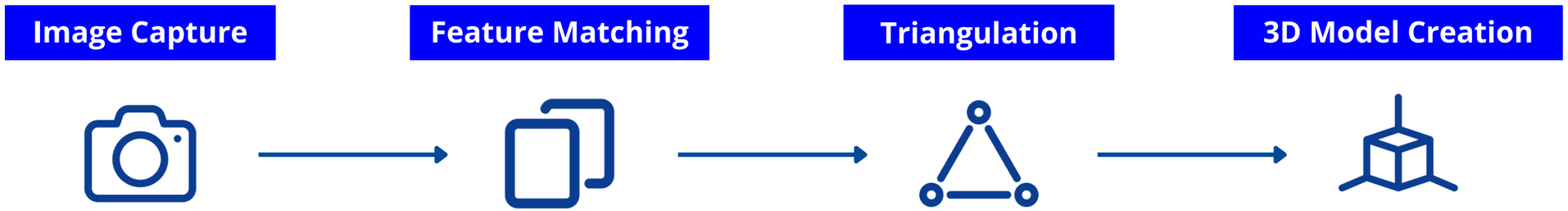
3D printed, stepper motor, Arduino-controlled

- **Lighting:**

LED panels/strips, white sheets for background masking

3D mesh from photos

1. Image Capture: Take multiple overlapping photos of the object or area from various angles.
2. Feature Matching: Software identifies common points or features across different images.
3. Triangulation: Uses geometry to calculate the position of points in 3D space based on camera positions.
4. 3D Model Creation: Combines all points to form a 3D model, adding texture and detail.



STARscan uses Meshroom from AliceVision for photogrammetry-based 3D reconstruction [1].

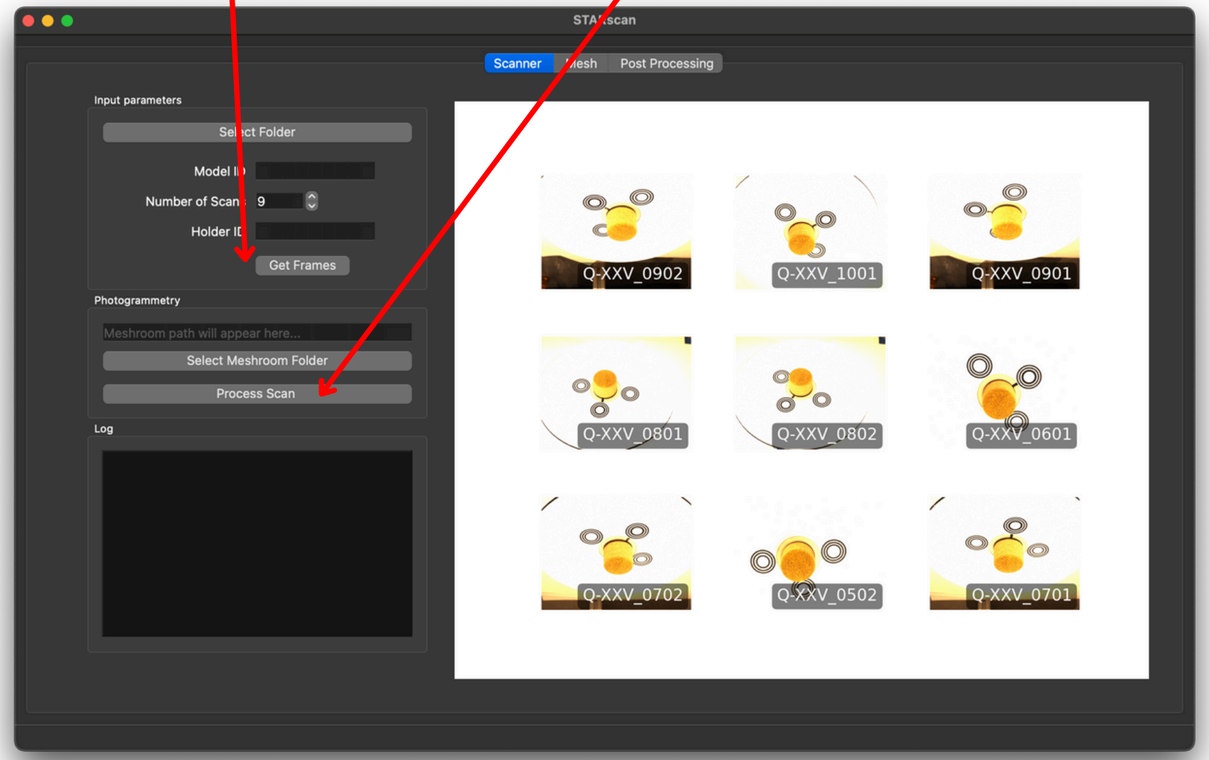
[1] AliceVision Meshroom. Available at: https://alicevision.org/#meshroom

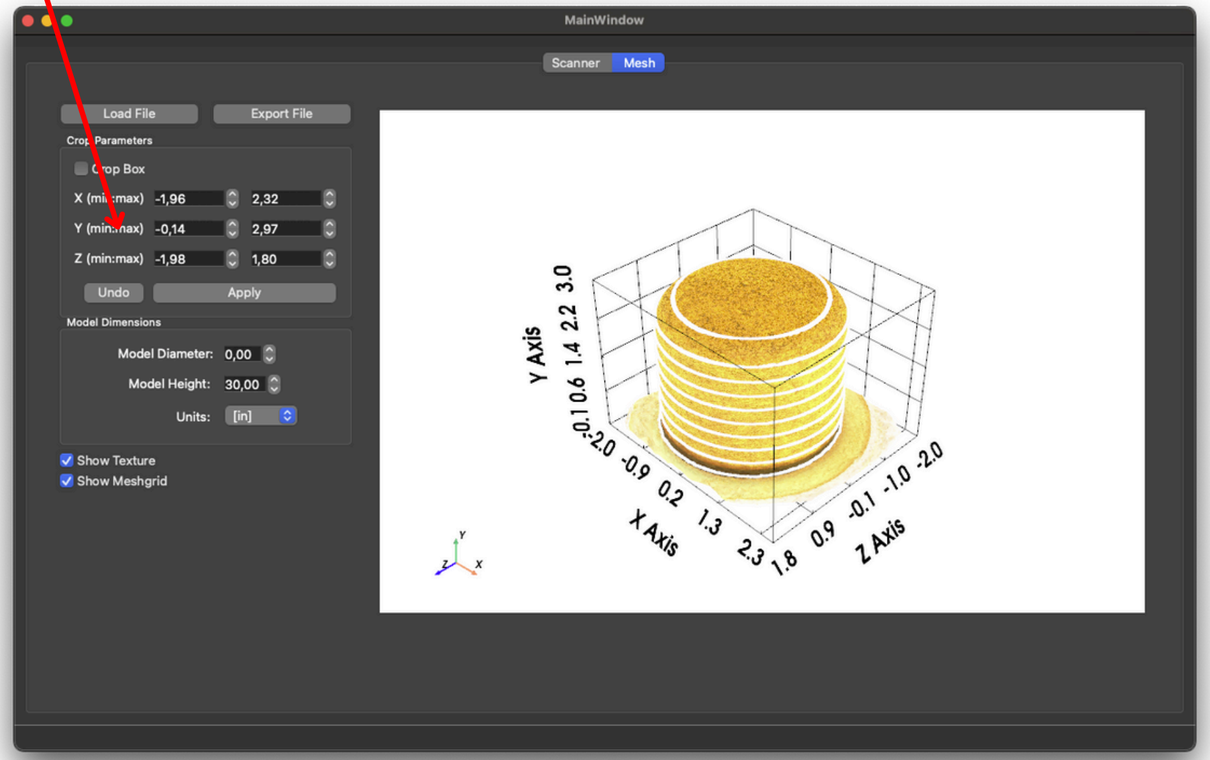
STARscan GUI

1) Get the frames

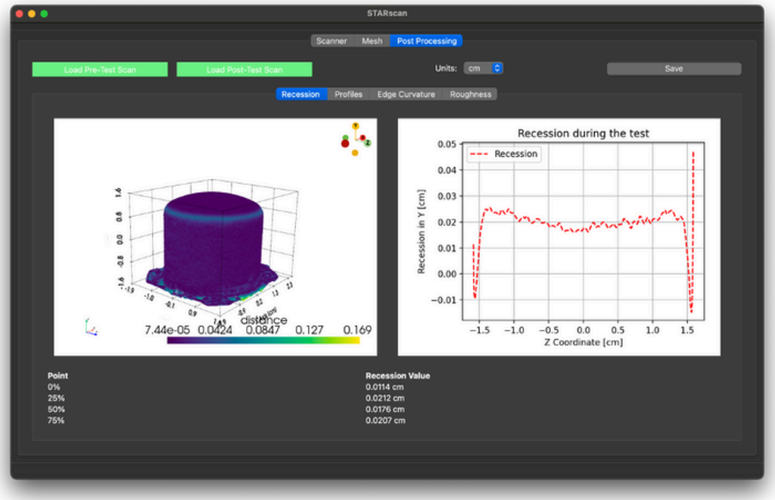
2) Generate Mesh

3) Crop

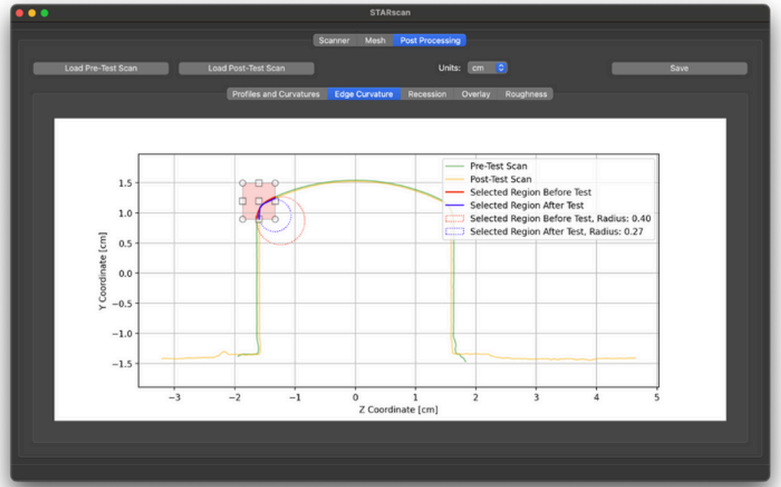




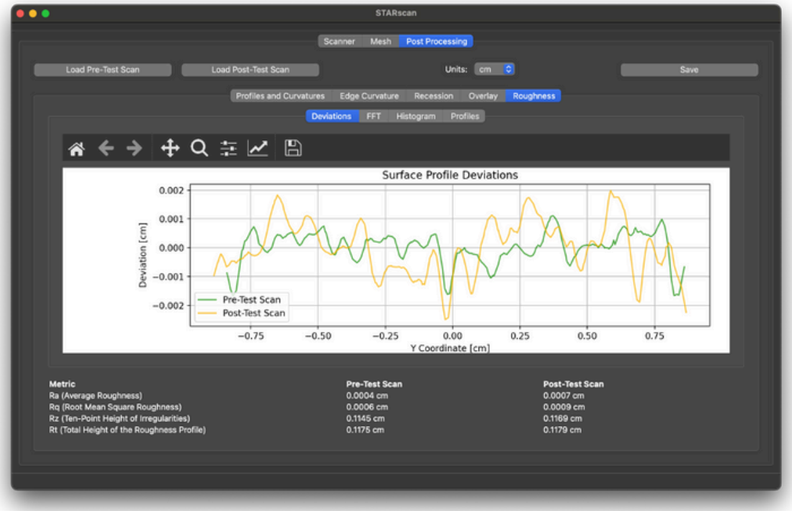
STARscan GUI: Post-processing



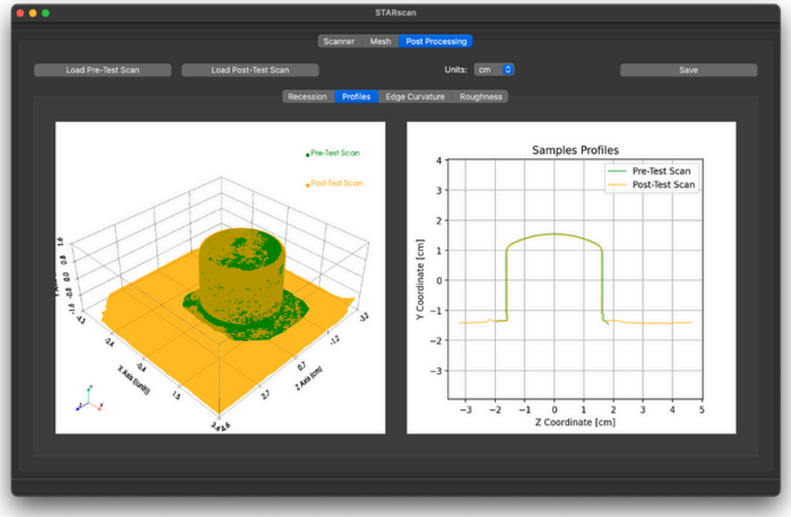
Recession



Shoulder Curvature



Roughness



Profiles

8. Conclusion

arcjetCV:

- New Class
- Expanded Dataset
- New Architecture
- 3 installation ways

ArcjetCV enables:

- Automated recession statistics
- 2D model validation
- Time resolved validation

STARscan:

- 2 scanners
- 1 User interface
- 4 Postprocessing features

STARscan enables:

- Automate 3D reconstruction, imaging, alignment and analysis.
- Eliminate pretest imaging and 3D scanning bottleneck.

→ Better mission planning and risk management

Acknowledgments

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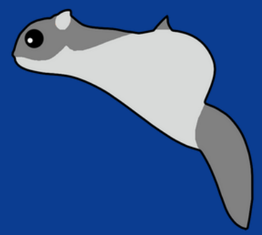
- MSR
- ESM
- TSM Branch IRAD

Thank you for your attention !



Get updates of
STARscan and **arcjetCV**