miniSTARscan: A Portable 3D Photogrammetry Rig for Arcjet Sample Scanning

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Abstract

Pre- and post-test scanning of samples exposed to arcjet and other high-enthalpy facilities is essential for quantifying material ablation, surface curvature, and roughness evolution. Conventional high-fidelity 3D scanning solutions—such as handheld laser scanners or large photogrammetry rigs—are costly, require the use of proprietary software, and are not tailored for high-throughput standardized scanning.

The miniSTARscan system is a compact, automated, and portable photogrammetry-based scanner designed to achieve sub-millimeter accuracy. The rig combines three compact cameras with lightweight 3D-printed components, an aluminum frame, and modular LED lighting, enabling high-throughput scanning (sub-minute scans) at test facilities with tailored data pipelines. A dedicated graphical user interface automates calibration, image acquisition, 3D reconstruction, 3D mesh texture (e.g., colored mesh), alignment of pre- and post-test geometries, and several standard measurements (recession map, profile extraction, radius of curvature, and surface roughness).

miniSTARscan will be released with an open-source hardware and software, providing a low-cost, highly-customizable alternative to commercial scanners. Its companion software is simple to use, integrates with common photogrammetry libraries, and interfaces directly with the in-house database (ArcBEAST) for streamlined data management and further analysis.

This combination of built-in analysis tools, affordability, and high-throughput enables repeatable high-quality scanning, standardizes detailed surface analysis, and eliminates scanning bottlenecks in facility operations.

keyword: *Recession tracking, photogrammetry, arc-jet, plasmatron, 3D reconstruction, portable scanning.*

Scanner Software Updates

- New! **Calibration tab**
  - Focus optimization assistant
    - Live preview with user selectable ROI for each camera
    - Realtime quantified sharpness with focus score = Var($\nabla^2 I$)
      - I is the grayscale ROI
      - $\nabla^2 I$ is the Laplacian (second derivative)
      - Var(·) denotes the variance
      - Higher values indicate sharper focus
    - Enables user to dial in optimal focus via trend arrows and normalized scores
  - Set automated exposure times
  - Ensures scan FOV includes sufficient calibration patterns
  - CCTags and April tags are used for calibration
- **Scanner tab**
  - Improved control & calibrated rotations of turntable
  - Shows tiled representation of acquired images
  - Supports external library reconstruction via Meshroom and RealityCapture
- **Mesh tab**
  - Displays reconstructed mesh
  - Color mesh by elevation or original images
  - Zoom, rotation, & cropping tools
- **Post Processing**
  - **Recession**
    - Requires pre-test and post-test meshes
    - subtracts the aligned meshes to give height map
  - **Curvature**: interactive ROI allows measurement of global or shoulder curvature
  - **Roughness**: added standard surface roughness metrics (Ra,Rq,Rz,Rt)
  - **Extract Profile**: extract axisymmetric 2D height profile

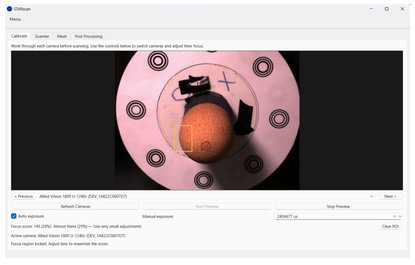


Figure 1: Calibration tab of the STARscan GUI.

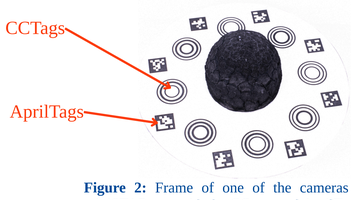


Figure 2: Frame of one of the cameras of miniSTARscan with the CCtags and AprilTags.

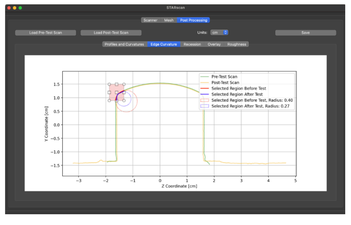


Figure 3: User-selectable ROI for curvature measurements. Allows pre/post test mesh to be compared directly as well

Scanner Hardware Updates

- **Simpler hardware**
  - Uses 3 instead of 6 cameras and makes use of the turntable to acquire more images
  - Design uses standard 20x20x200 mm t-slotted rails instead of 25x25 mm x-sections with varied lengths.
- **Improved alignment**
  - Sample turntable is fixed to camera rig for consistent imaging/focus
  - Smaller camera rig optimizes for standard 1-4" diameter samples
- **Additional Calibration Patterns**
  - Uses both CCtags and April tags to be compatible with both Meshroom and RealityCapture
  - Tags built into turntable platform for auto-calibration every scan
- **Lighting improvements**
  - Lighting is now mounted onto the rig instead of on separate independent posts (more consistent lighting)
  - Posterboard light box more consistent than paper backing

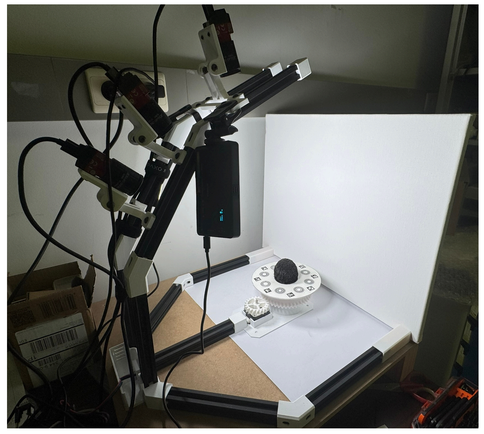


Figure 4: The miniSTARscan system installed at the von Karman Institute for Fluid Dynamics.

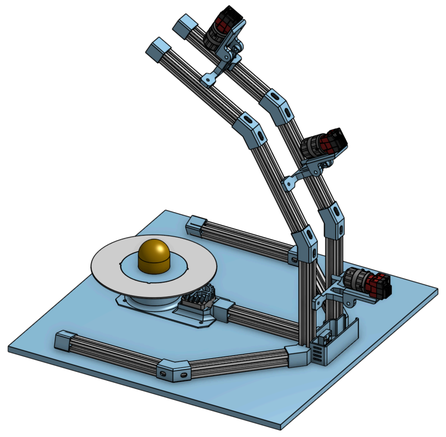


Figure 5: CAD model of the miniSTARscan setup configured to scan a sample with 50 mm diameter.

Structure-from-Motion (SfM)

At the core of miniSTARscan is a photogrammetric technique known as Structure-from-Motion (SfM) — a process that reconstructs 3D geometry from a set of overlapping 2D images taken from different viewpoints.

The SfM pipeline follows these key steps:

1. **Image Capture:** the sample is placed on a turntable and imaged from multiple angles using three calibrated cameras. As the turntable rotates, synchronized images are acquired at fixed intervals.
2. **Feature Detection and Matching:** distinctive visual features (corners, textures) are automatically detected in the images and matched across views.
3. **Camera Pose Estimation:** using these matches, the system computes the relative positions and orientations of the cameras with respect to the sample.
4. **Triangulation and 3D Point Cloud Generation:** corresponding 2D features are triangulated into 3D space, forming a sparse point cloud that represents the sample's surface.
5. **Mesh Reconstruction and Texturing:** the sparse point cloud is converted into a full 3D mesh, which is then textured using the original images to provide color detail.

By leveraging this approach, miniSTARscan produces accurate, repeatable 3D reconstructions using low-cost hardware and open or commercial SfM tools. Calibration is performed beforehand using CCTags (for Meshroom) or AprilTags (for RealityCapture), allowing reconstructions to be geometry-aware and correctly scaled.

Results

50mm samples scans

A cork sample was scanned before and after plasma exposure. The difference in surface geometry was computed along the surface normals, highlighting material recession and swelling with sub-millimeter resolution.

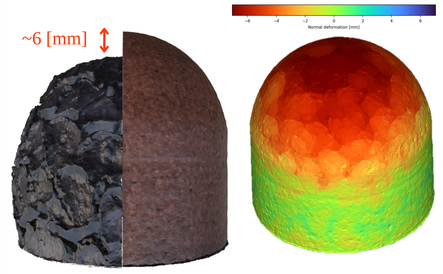


Figure 6: Pre- and post-test scans of a cork sample from the Von Karman Institute after exposure in the Plasmatron facility.

Figure 7: Normal displacement between the pre-test and post-test scans, visualized using a color gradient.

Future work

Future work will focus on enabling in-situ 3D reconstruction of Arctron and Plasmatron tests using synchronized multi-camera acquisition. A proof-of-concept was developed during a collaborative summer project between VKI and NASA Ames, demonstrating pre-calibrated multi-camera imaging inside the NASA Arctron chamber. The long-term goal is to combine the high-resolution 3D capabilities of STARscan[1,2] with the time-resolved tracking of arcjetCV[3,4], enabling continuous geometric monitoring during high-enthalpy tests. Upcoming efforts will target improving robustness under plasma conditions and deploying the system for time-resolved 3D reconstructions.

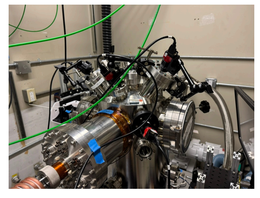


Figure 7: In-situ 3D reconstruction setup for the ARCTRON facility at NASA Ames Research Center.

References

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