

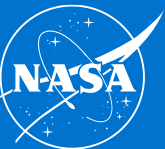
3D Body Scanning for Space Anthropometry: Technology Exploration and Development

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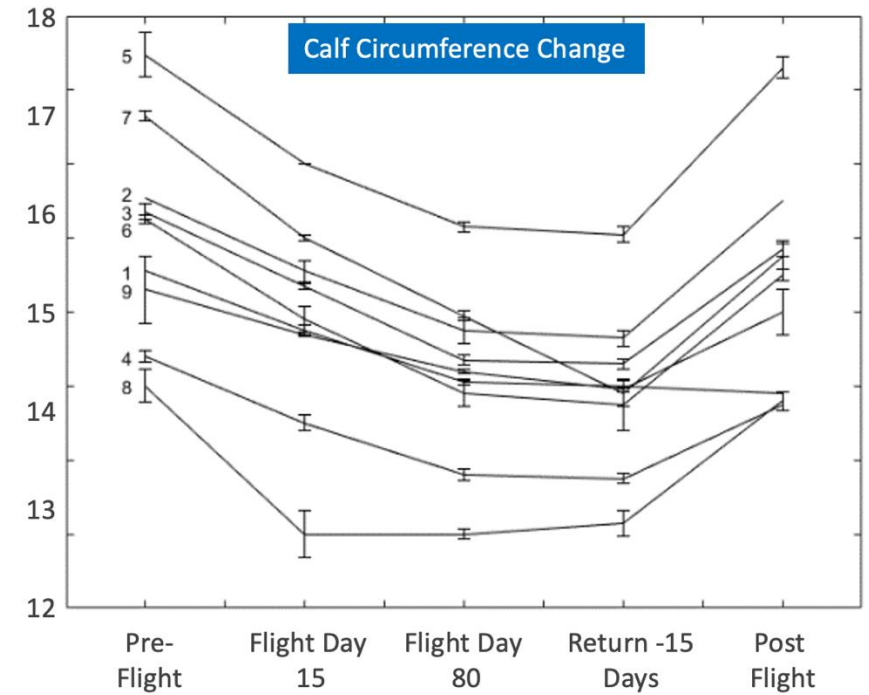
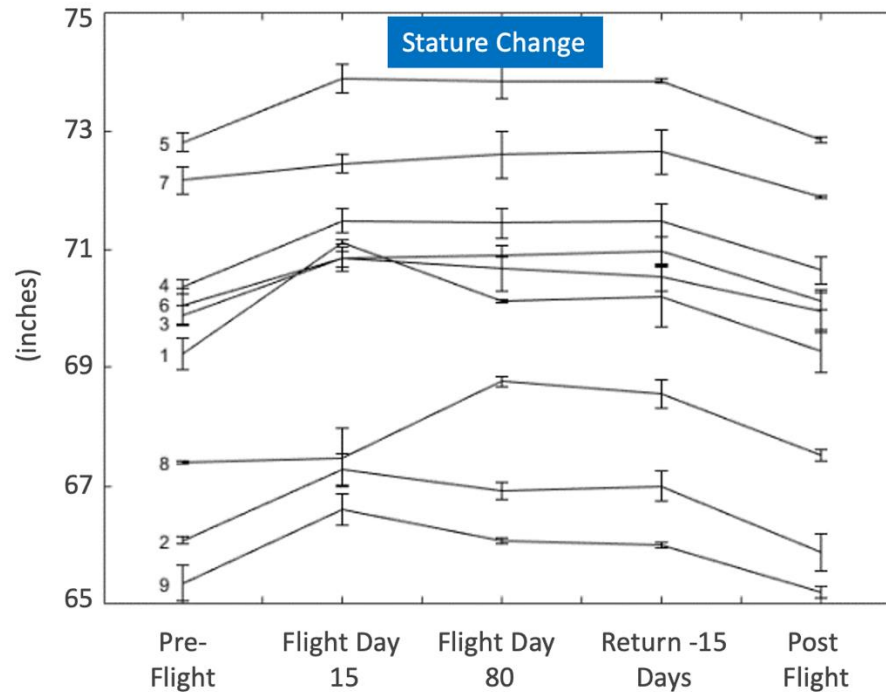
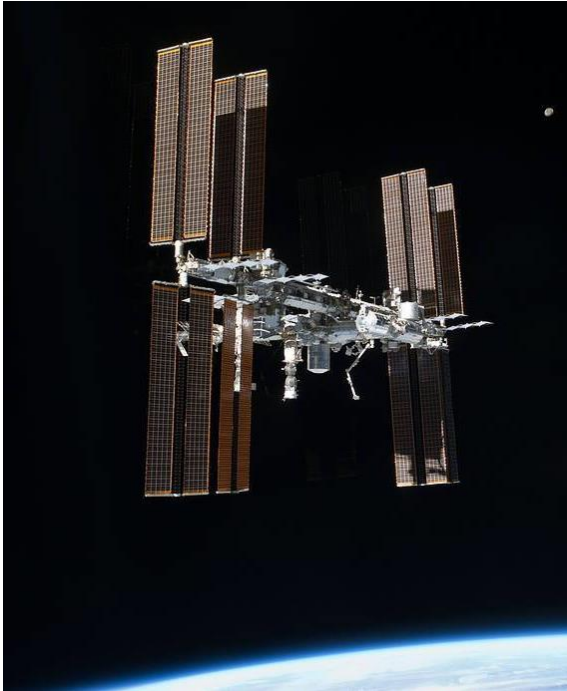
Artificial Intelligence (AI) Usage Disclosure

This document was created with assistance from Microsoft CoPilot for image retouching, including object highlighting, vendor and subject deidentification and background removal. The content has been reviewed and edited by KH Kim.



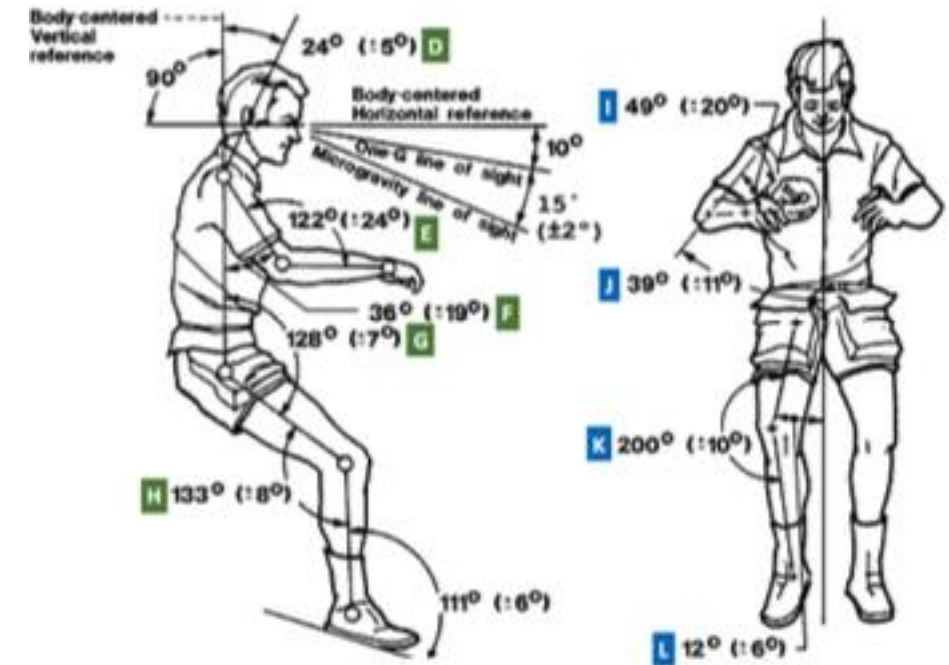
Background: Anthropometry Changes in Spaceflight

- Different gravity level uniquely changes body shape by spinal elongation, fluid shifts, and muscle atrophy
- On-orbit microgravity anthropometry was evaluated across Space Shuttle and International Space Station (ISS) missions
- Measurement techniques in microgravity differ from ground-based methods, making consistent comparison difficult



Background: Neutral Body Posture

- Human body in 0-g also shows a unique posture (neutral body posture; NBP)
- The early designs for spaceflight hardware were based on upright standing or sitting postures without consideration of NBP, resulting in crew discomfort.
- However, direct 3D measurements of NBP have not been available



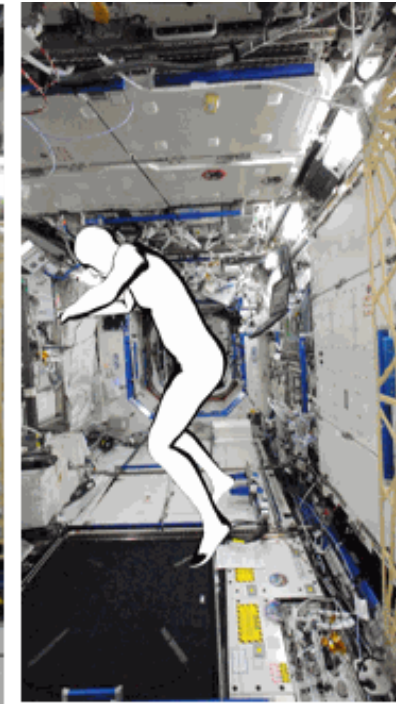
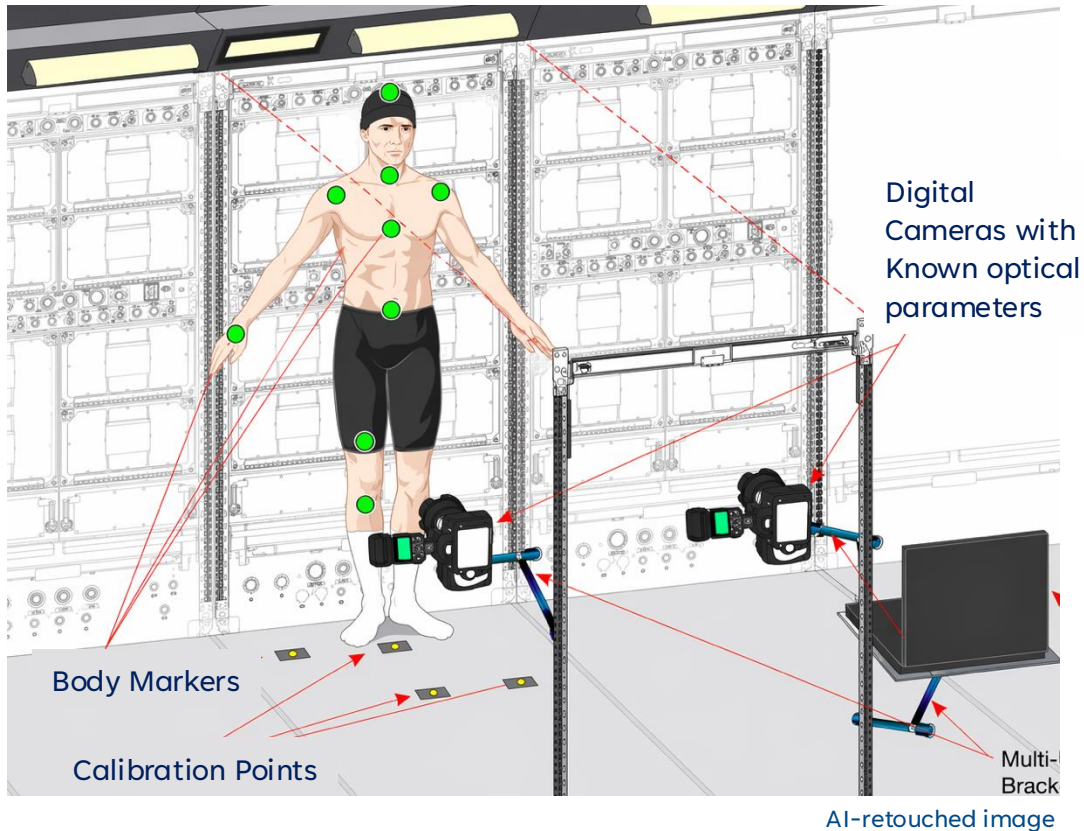
NASA-STD-3001

Aims of the Work

- Develop a 3D body scanning system that can accurately capture anthropometry and body-shape changes during spaceflight
- Define requirements and identify technical challenges for in-flight deployment and operations
- Explore and demonstrate proof-of-concept technology for an in-flight 3D body-scanning system

Past Work

- The ISS study (2013–2017) used two digital cameras with known optical parameters, then extrinsically calibrated to interior panel points to triangulate body-marker positions
- Stereophotogrammetry estimated 3D body shape in neutral posture by manually reposing subject-specific 3D scans to align with camera image



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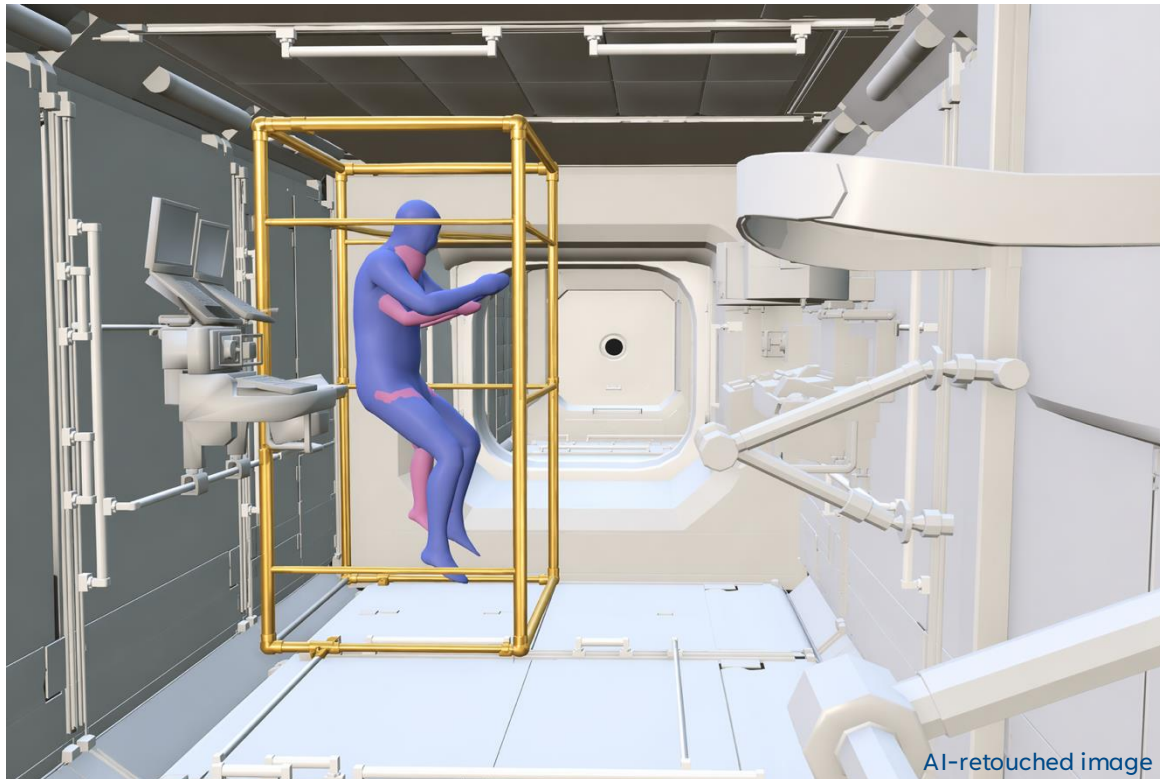


New System Requirements & Technical Challenges

1. Limited Volume for 3D Scan hardware

- Initial design concept used a phone-booth type scanner
- However, most spacecraft and flight hardware cannot accommodate this footprint

Initial Concept



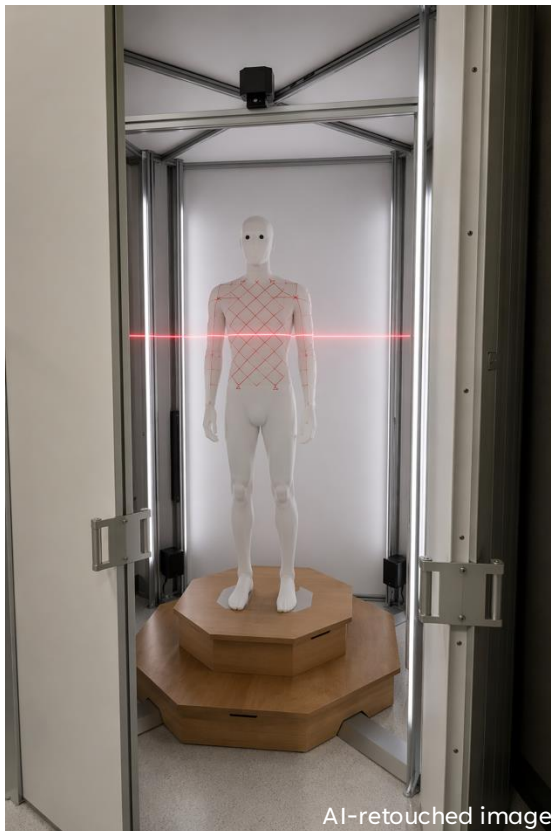
ISS Interior



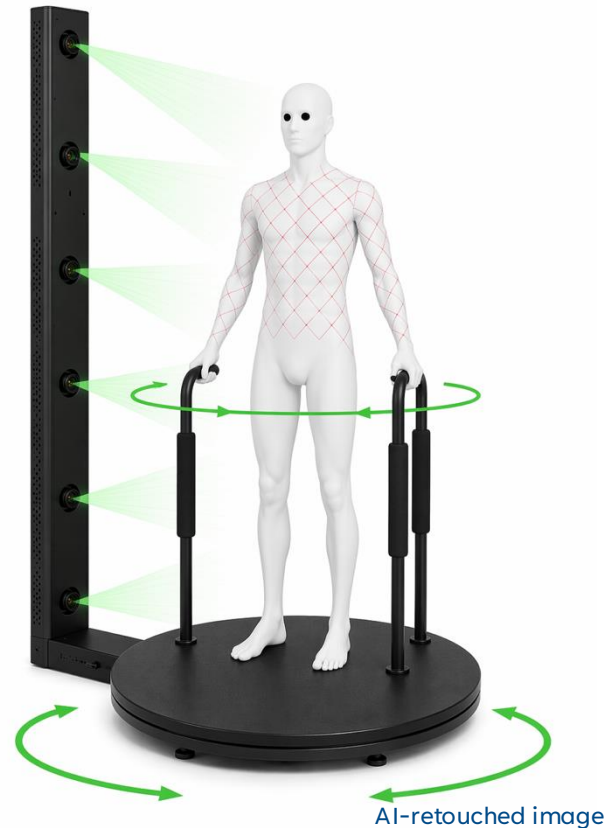
New Development: Requirements & Constraints (Cont'd)

Although these scanner types are known to deliver high-quality results, they are difficult to deploy in space vehicles due to footprint constraints

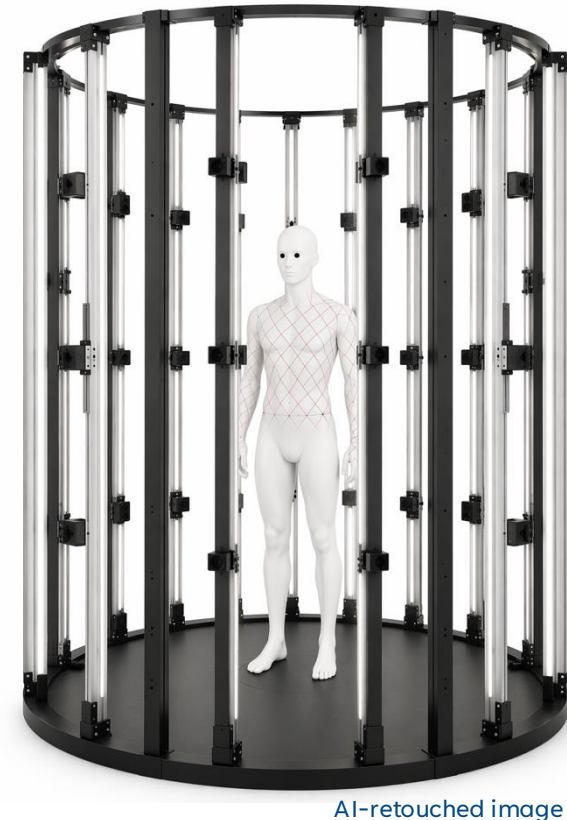
Laser Scanning Booth



Turn Table Body Scanner



Multi-View Photogrammetry System



New Development: Requirements & Constraints (Cont'd)

2. Limited Crew Motion Control in Microgravity

- In microgravity, maintaining controlled motion is extremely difficult
- The slow/regulated circling motion needed for structure-from-motion (SfM) scanning is difficult to perform
- Full-body scans take 3–4 minutes, making them impractical for a subject drifting in microgravity



New Development: Requirements & Constraints (Cont'd)

Due to the limited motion control, the following scanner types were tested but found to be impractical

Mobile Device 3D Scanner



Hand-held scanner



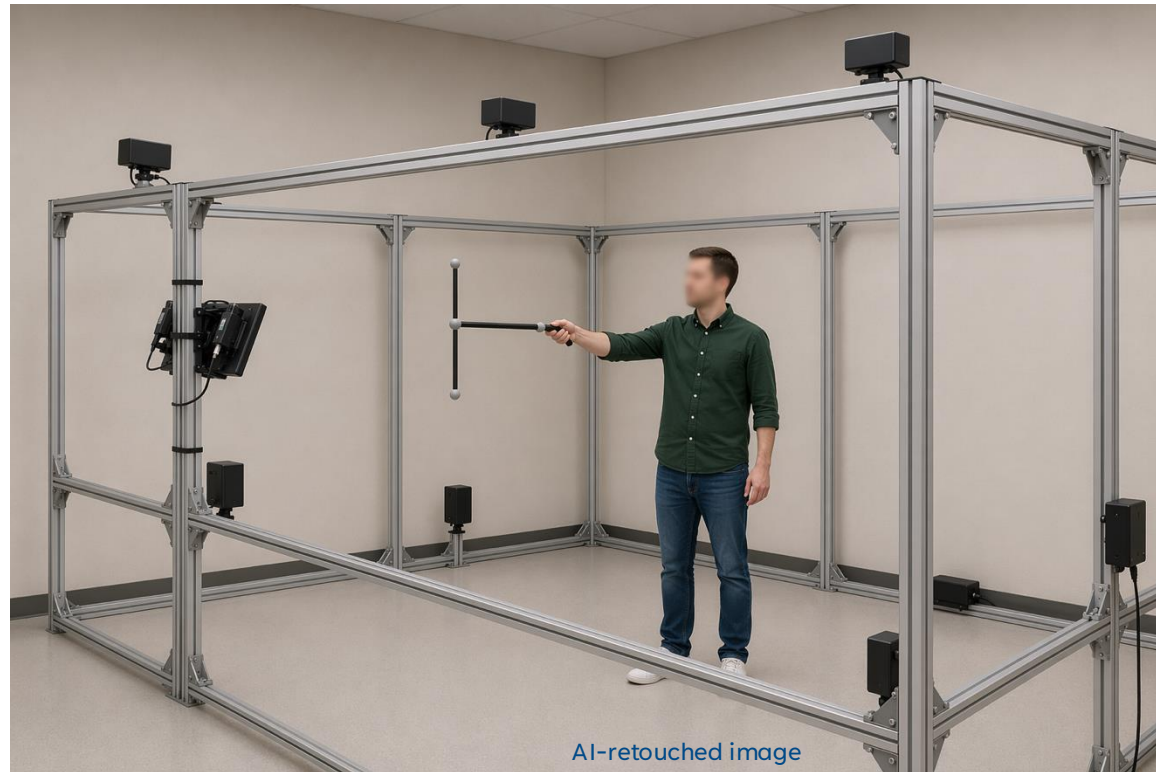
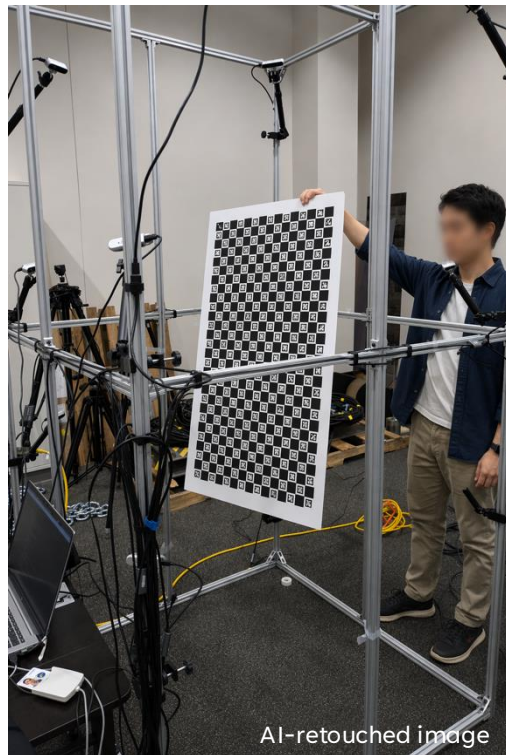
Terrestrial Laser Scanner



New Development: Requirements & Constraints (Cont'd)

3. Calibration Difficulty

- Space constraints and limited motion control make traditional pre-scan calibration methods impractical
- Even if calibration is achieved temporarily, sensors can be easily bumped in microgravity, causing immediate loss of calibration



Other Crucial Requirements

- **Flight certification** (typical costs 200K-600K USD): Must pass environmental and safety qualifications, including launch vibration, G-loads, materials outgassing/flammability, and electromagnetic compatibility
- **Minimal mass:** Each additional pound mass costs +5,000-10,000 USD to transport
- **Simple Installation:** “snap-on” installation is desired, without special tools
- **Easy operation and minimal training:** requires an efficient and intuitive user interface
- **All local data processing:** NASA policy restricts cloud storage or processing of certain data types
- **Radiation proof:** Some optical and inertial sensors degrade under prolonged space radiation
- **Medical grade precision:** NASA requires approximately 3-5 mm scan-to-scan reliability and 20 mm body measurement consistency

NASA In-House Development for Tech Demo: Main Principle

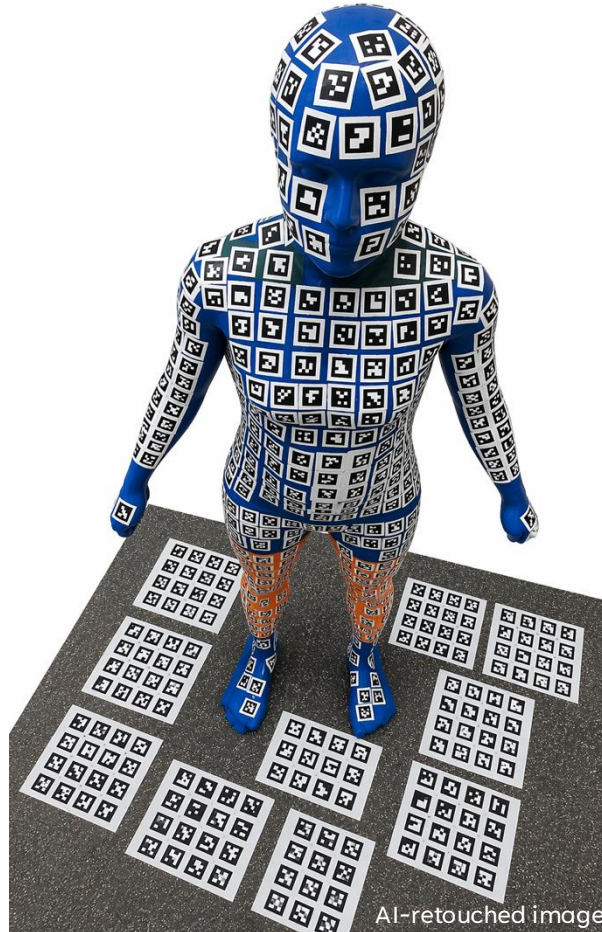
1. Use single hand-held RGB-D sensor (Intel RealSense D435)

2. AruCo markers on body and floor for multi-view extrinsic calibration

New method for self-calibration, without using structure-from-motion (SfM)

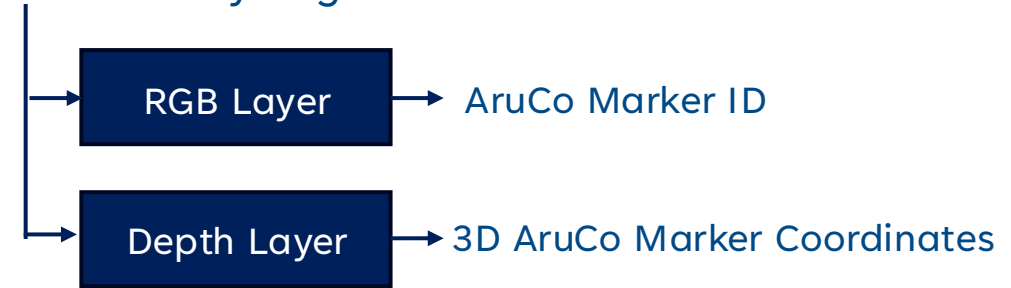


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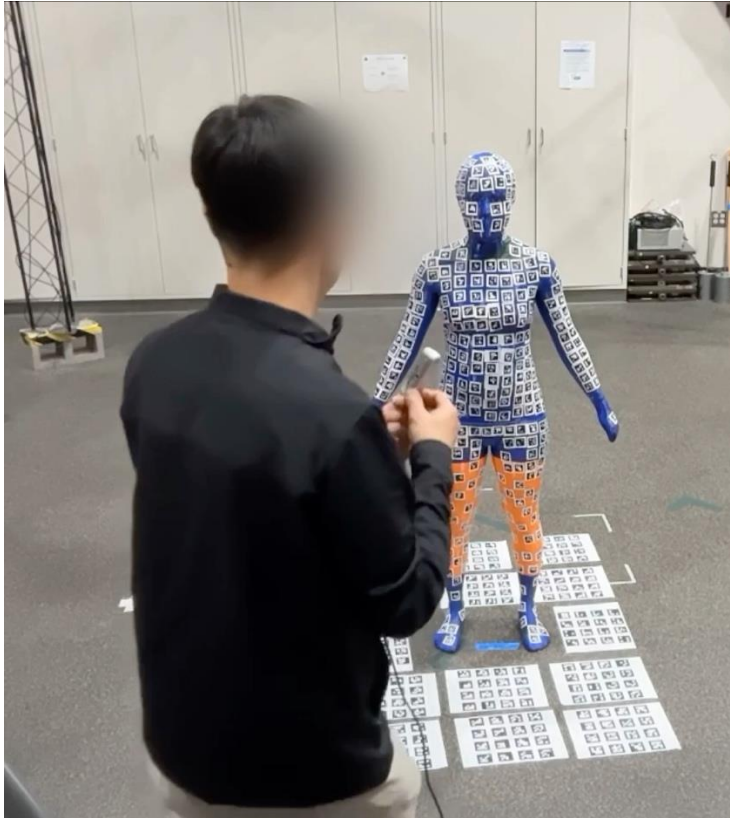
RGB-D Body Segment Scan Frame



- Once the sensor provides registered depth points, multiple segment-scan frames are stitched by matching the 3D ArUco coordinates across views
- This method virtually eliminates the need for calibration, controlled sensor maneuvers required in SfM and large-footprint scan hardware

Workflow and Data Examples

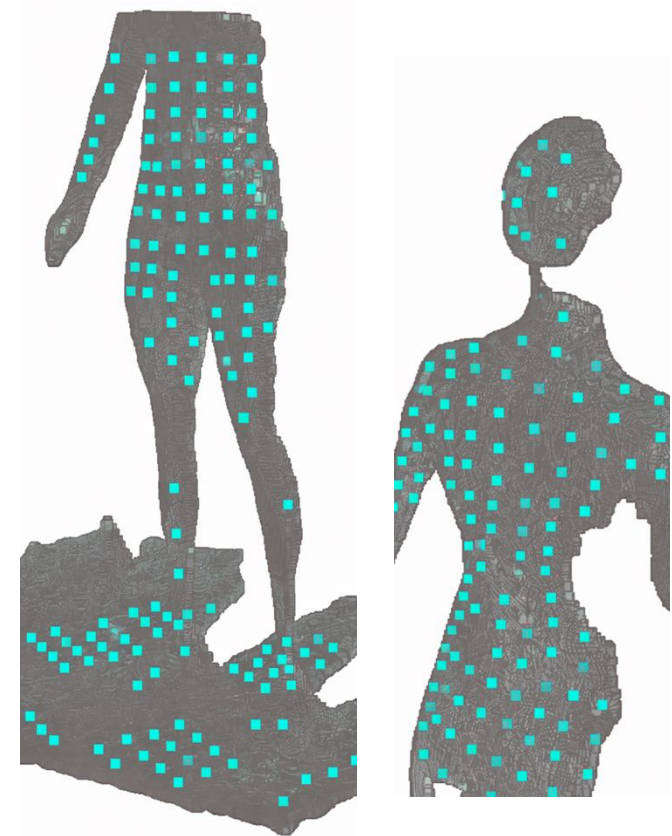
Multi-view static shot capture
(no controlled continuous motion)



AruCo marker **unique IDs**
captured by OpenCV



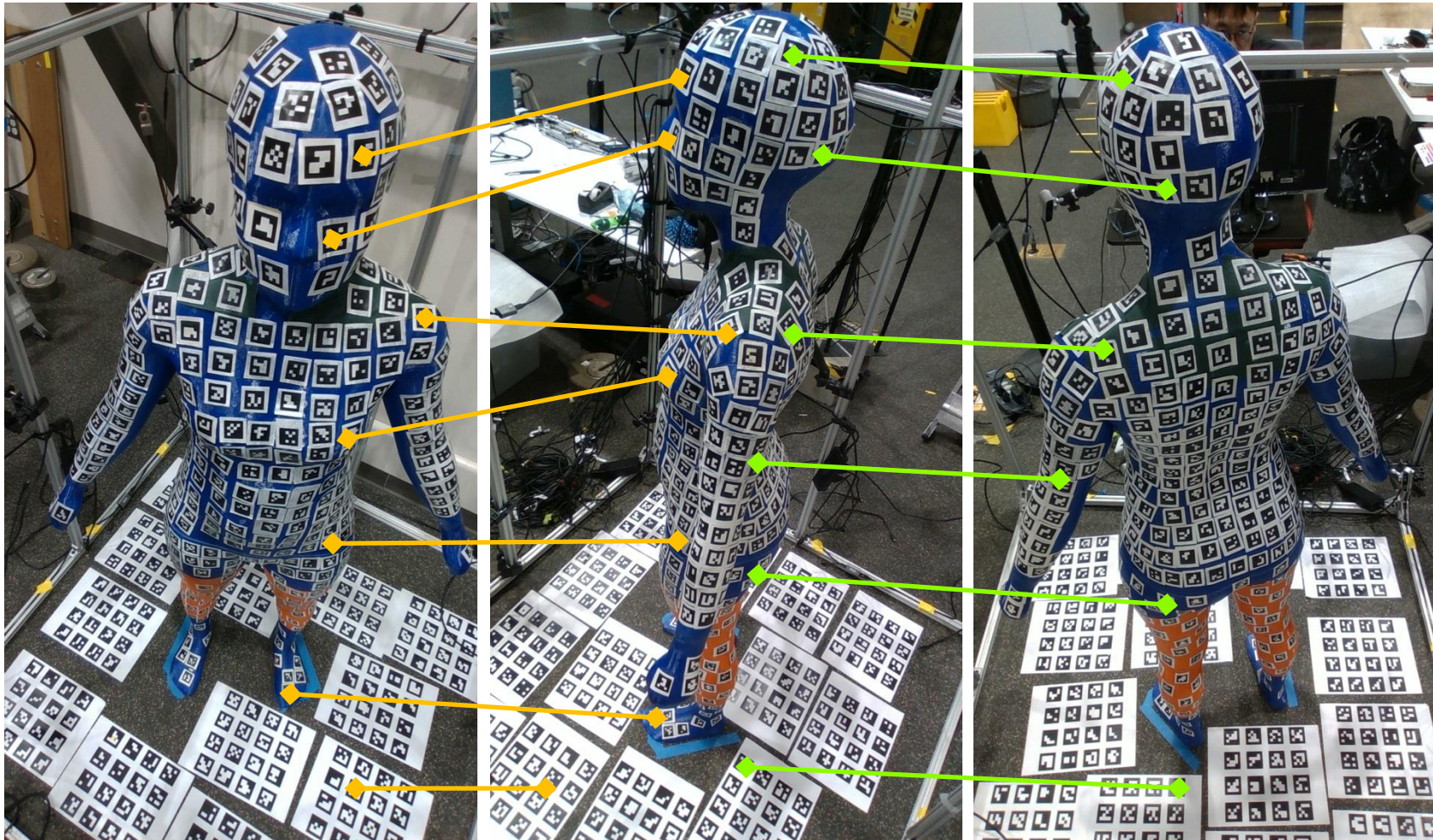
Depth data yields 3D point cloud of manikin with
corresponding 3D Aruco coordinates (**bright dots**)



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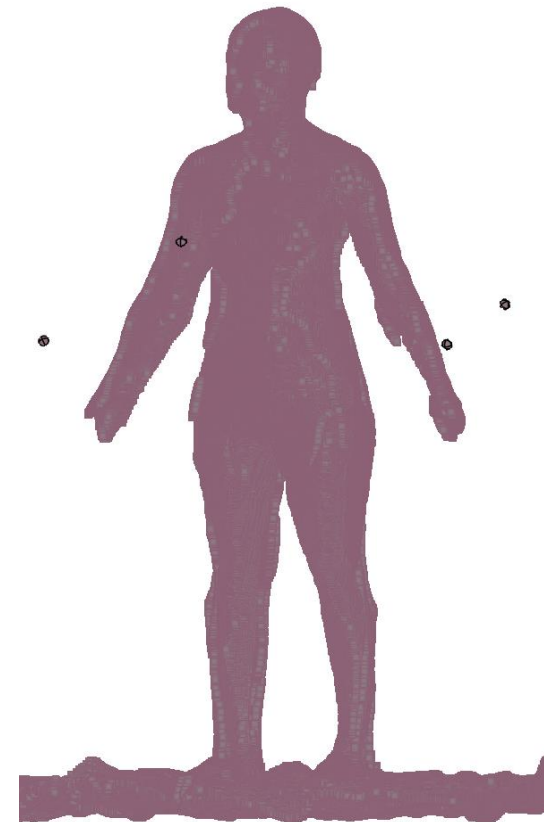
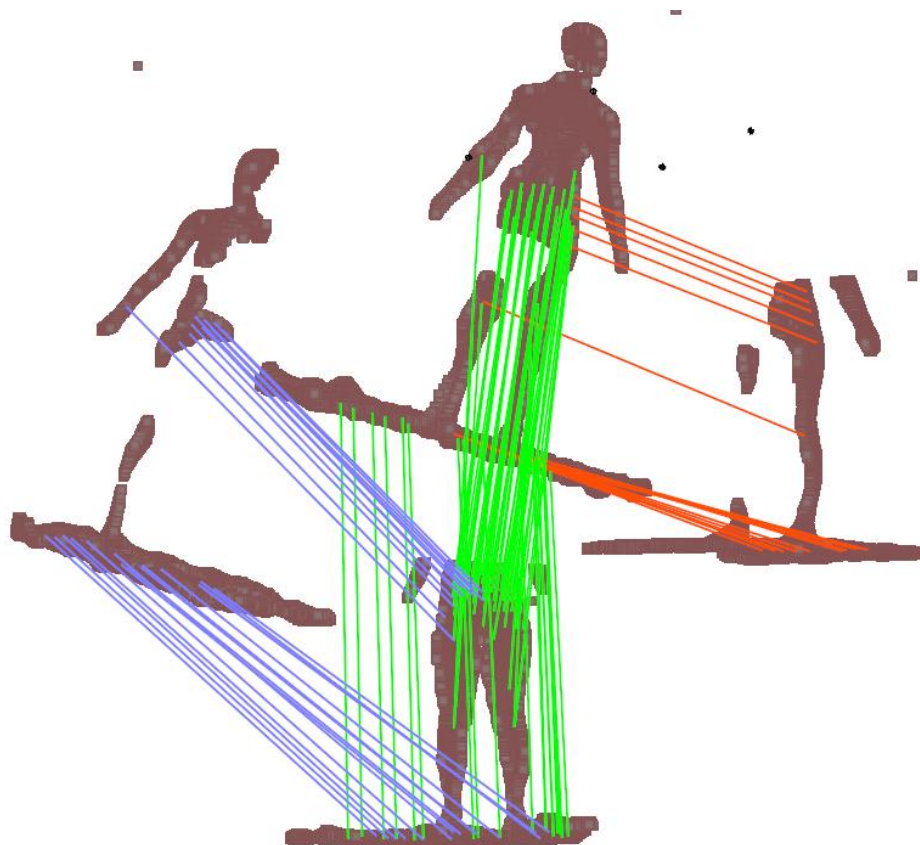
AruCo Marker ID Matching

RGB-layer ArUCo marker IDs are matched across frames to establish frame-to-frame correspondence



3D Point Cloud Alignment by Aruco Correspondence Mapping

- An optimization algorithm (e.g., Procrustes) estimates the position and orientation of each frame's point-cloud segment by minimizing distances between corresponding ArUCo markers
- The resulting transformations are applied to stitch the segmented point clouds into a unified 3D model



Mesh Reconstruction from Point Cloud

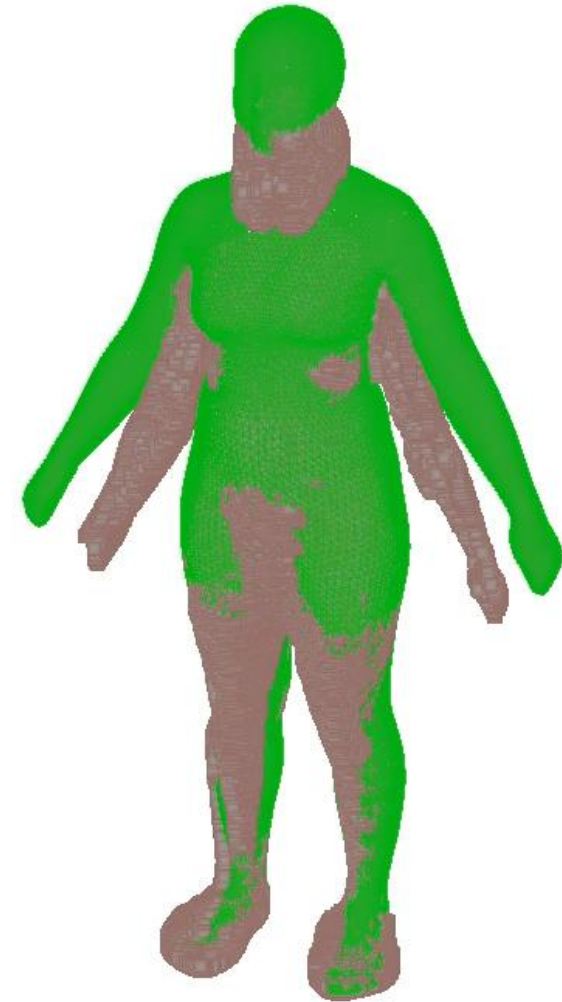
Aligned point cloud data still has substantial noise and imperfections requiring cleaning mesh reconstruction

Step 1: Coarse Fitting

- Low resolution mesh (~600 vertices) fitted to scan using Variational Autoencoder (VAE)
- VAE constrains solution to morphologically plausible body shapes from training database of 3D scans
- Iterative closest point (ICP) alignment optimized in 20-dimensional latent space
- Outputs: latent code representing body shape

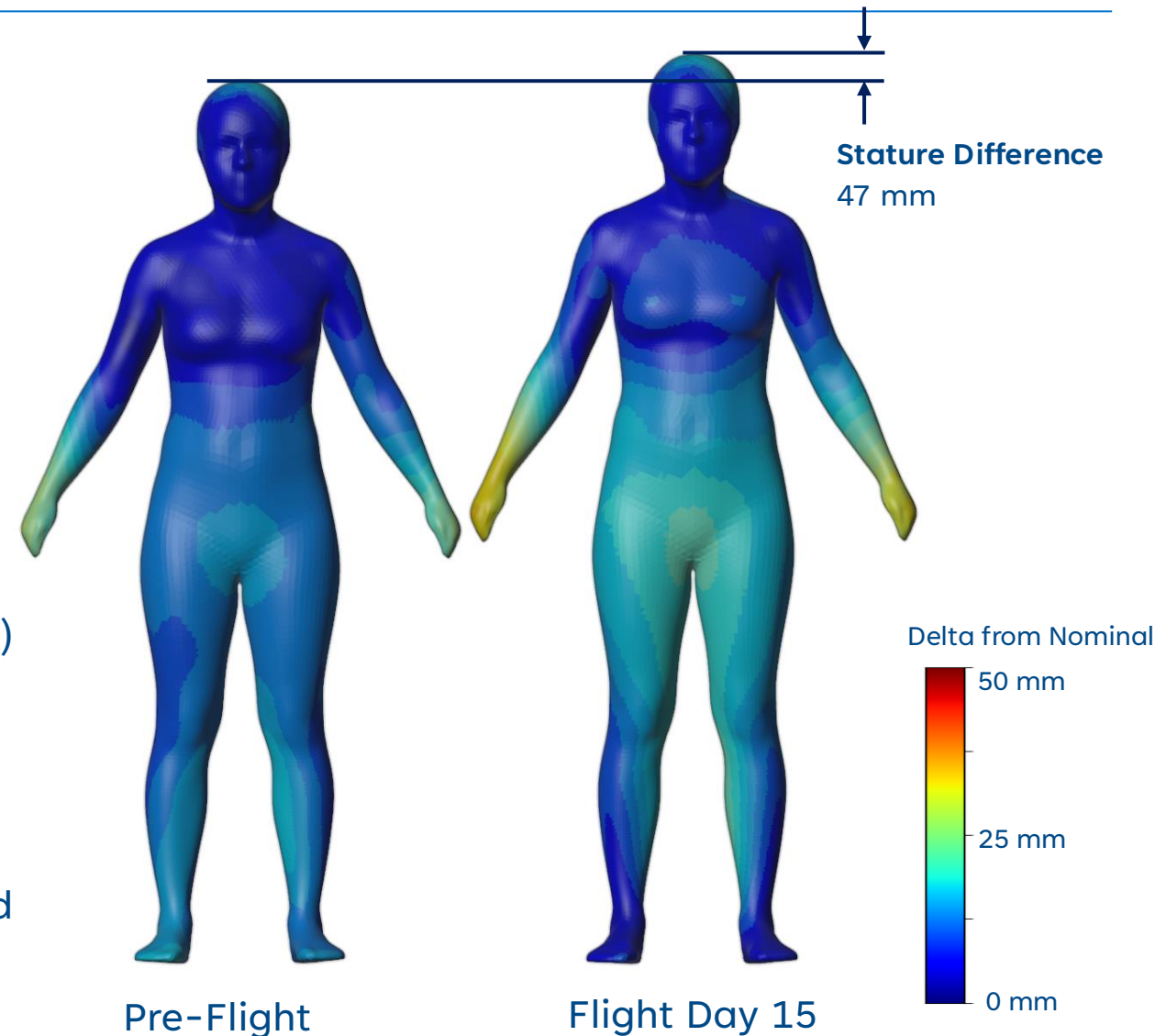
Step 2: High-Resolution Reconstruction

- Bayesian upsampling from low resolution (600 vertices) to high resolution (40K) mesh
- Preserves fine geometric details (curvature, surface features)
- Output: High-fidelity 3D body model



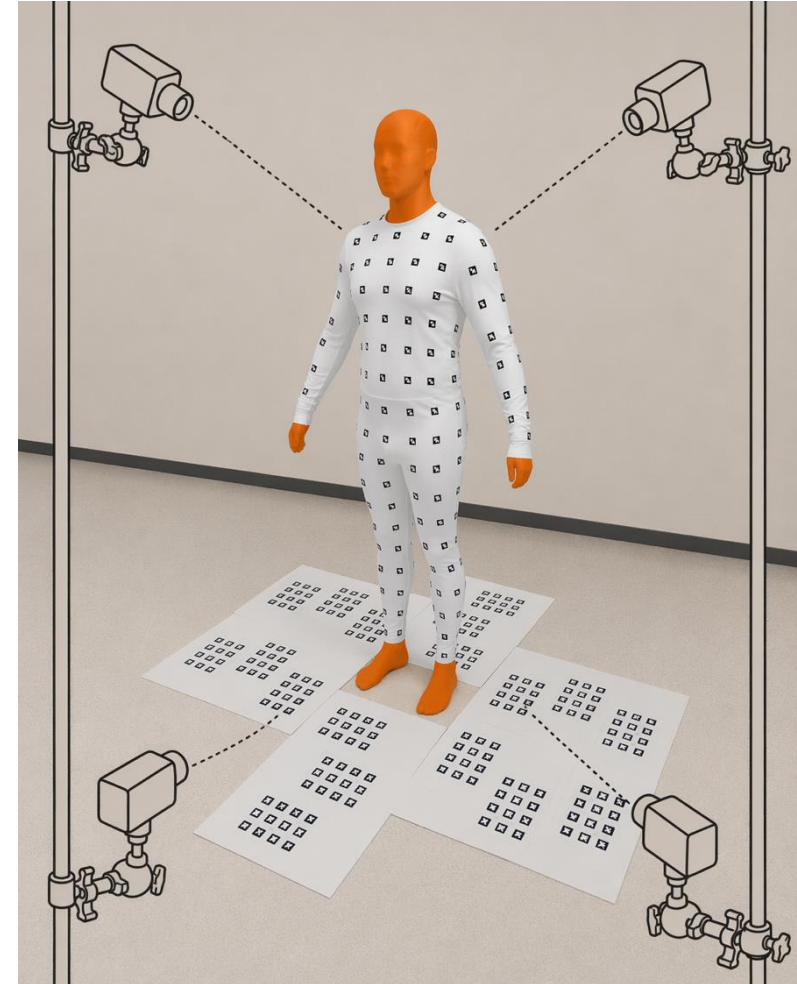
Reconstructed Scan Accuracy

- Two manikins were designed and 3D printed from ISS study results:
 - 1st percentile female stature, **pre-flight**
 - 1st percentile female stature, **flight day 15 (FD-15)**
- Scan performance was evaluated by comparing manikin scan surfaces to the nominal 3D-printed manikin CAD
- **Scan vs. CAD comparison** (Scan accuracy test)
 - Pre-flight manikin: 13.9 mm RMSE, 27.8 mm max error
 - FD-15 manikin: 17.8 mm RMSE, 35.6 mm max error
- **Pre-flight vs. FD-15** (Sensitivity to body shape change)
 - Compared to pre-flight, stature nominally increases by 46 mm (3%) by FD-15
 - FD-15 scan shows 47 mm larger stature than pre-flight manikin scan
- Results indicate overall satisfactory scan accuracy and sensitivity performance.



Discussion & Forward Work

- This work defined the requirements and technical challenges for an in-flight 3D body-scanning system
- Key design priorities include minimal hardware footprint, zero-calibration, and simple operation
- Developing an optimized spaceflight scanner will require new sensor and system capabilities
- This work demonstrated a NASA proof-of-concept to highlight a potential solution and engage industry
- Prototype scanner successfully detected in-flight anthropometry changes
- This system does not need calibration or controlled circling, but still requires multiple frame scanning with the subject remaining still
- Next step: marker-printed, form-fitting scan wear to reduce operational overhead
- Validated sensor locations can ultimately be embedded into vehicle or habitat interiors



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Acknowledgement

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