3D Scanning System to Assess Gravity-Dependent Body Shape Changes

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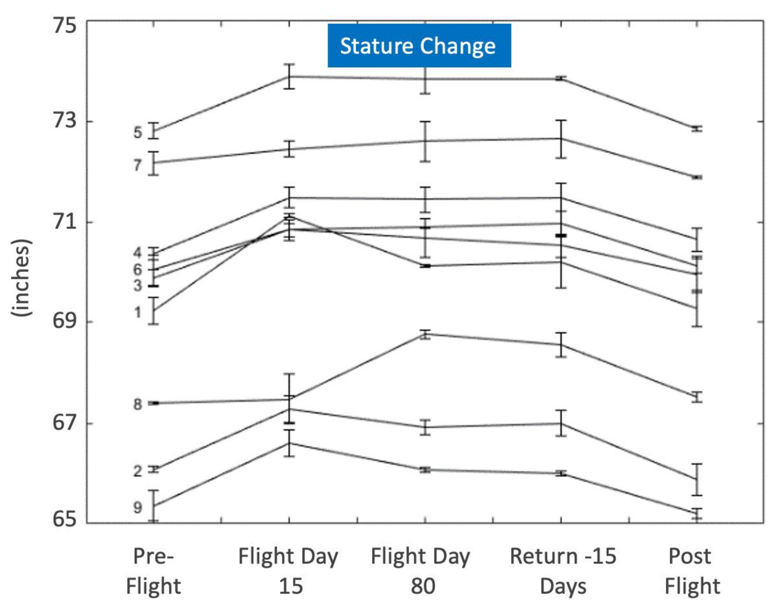
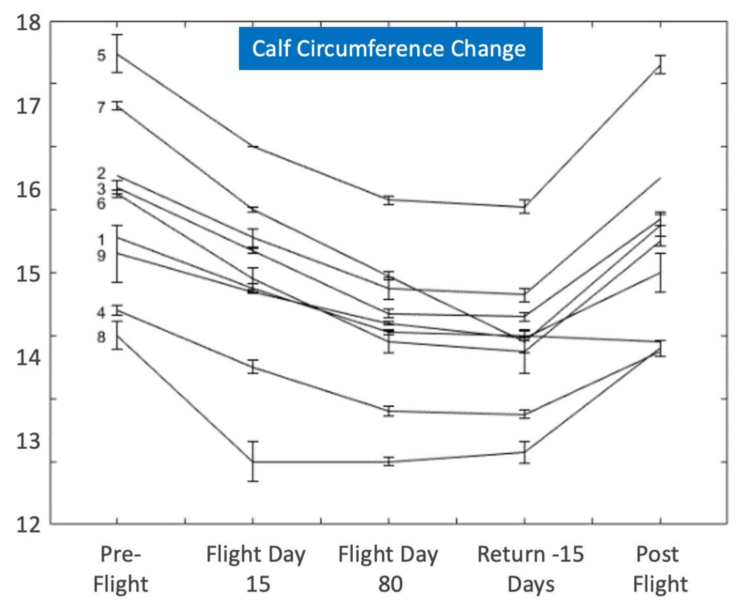
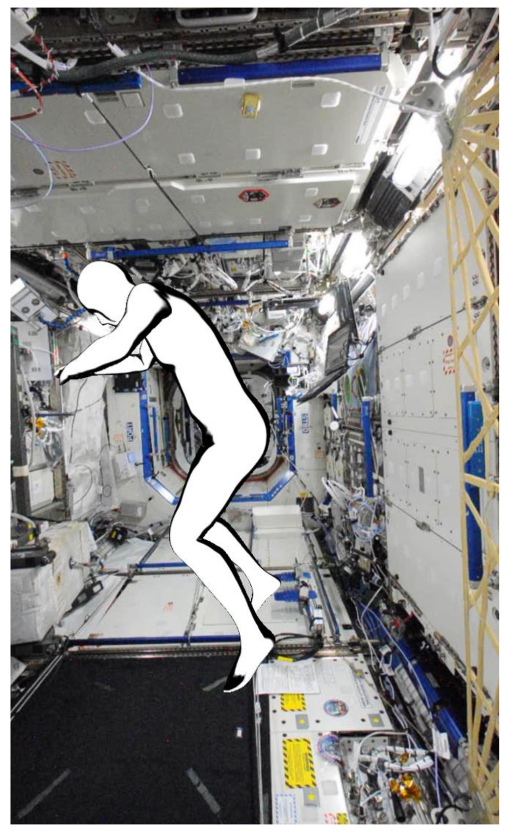
Background

- Different gravity environments change physical, physiological, and morphologic characteristics of the human body, including body shape and posture.
- Studies have shown characteristic anthropometry changes in Space Shuttle and ISS crewmembers; however, collected measurements were limited to lengths and circumferences without 3D volumetric information.





- Human body in 0-g also exhibits a unique posture (neutral body posture; NBP) when relaxed and when no external forces are applied.
- Maintaining a body posture other than NBP requires significant strength exertions. The early human interface designs were based on upright standing or sitting postures without consideration of NBP, resulting in crew discomfort.
- Newer system designs have adopted NBP as baseline, but the specific patterns or variations of NBP have not been clearly quantified.



- For in-flight body shape and anthropometry, 3D body scanning can provide unique advantages compared to traditional techniques based on a caliper or tape measure.
- However, 3D body scanning technology has not yet been made available for spaceflight or reduced gravity analogs.

Aims of the Study

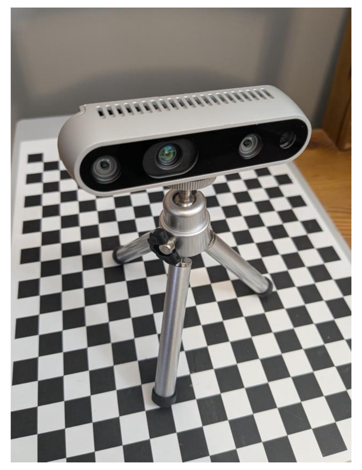
Develop a prototype 3-D body scanning system that is customized for in-flight use to scan crewmembers with the configuration and performance optimized for detecting known gravity-dependent body shape and posture changes.

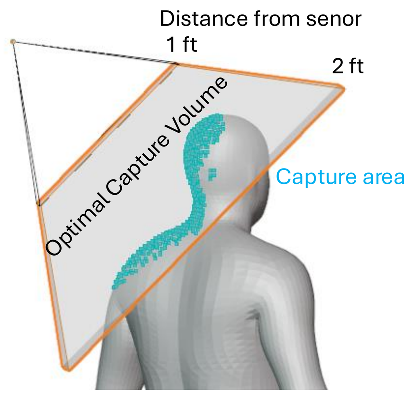
Aim 1. Develop Scan Hardware: Build a scanning system using commercial off-the-shelf 3D sensors. Optimize sensor configuration and design scan hardware to sensitively detect small changes in body shape and size.
Aim 2. Develop Scan Acquisition Software: Develop prototype scan acquisition software. Optimize software for efficient in-flight operations with minimal calibration overhead.
Aim 3. Assess System Performance: Test the scan system in the ground laboratory and compare the accuracy and reliability against a reference scanner.

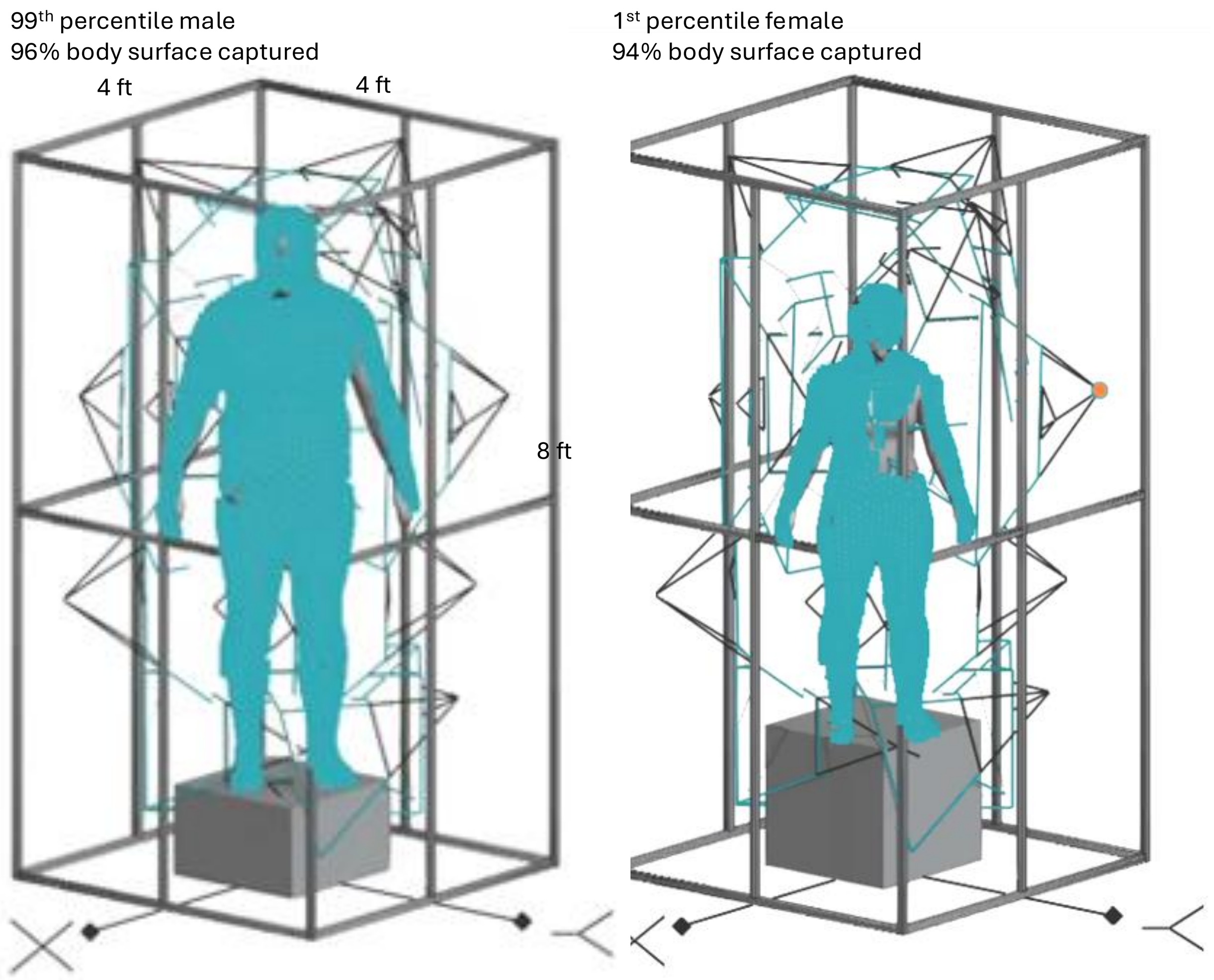
Development Methods & Results

1. Scan Hardware Development

- Used commercial off-the-shelf 3D sensors (Intel RealSense D415 and D435).
- Fabricated a 4x4x8 feet booth structure using 80/20 T-slot aluminum frames.
- A simulation determined how many sensors are needed and where the sensors should be mounted to ensure scan coverage with minimal gaps.
- The simulation indicated that 16 sensors can capture 96% of the body surface area from the 99th percentile male and 94% from the 1st percentile female body.

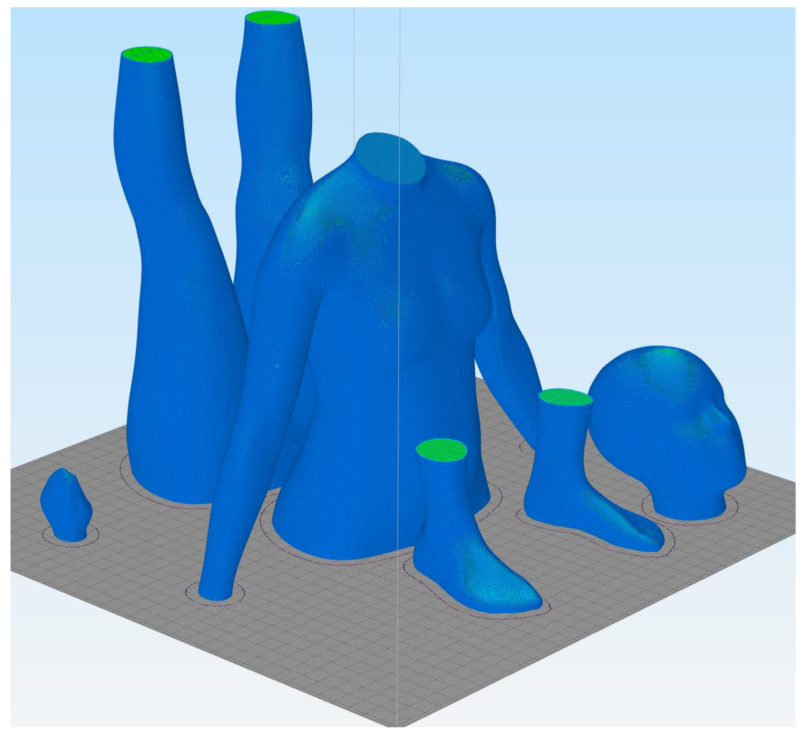






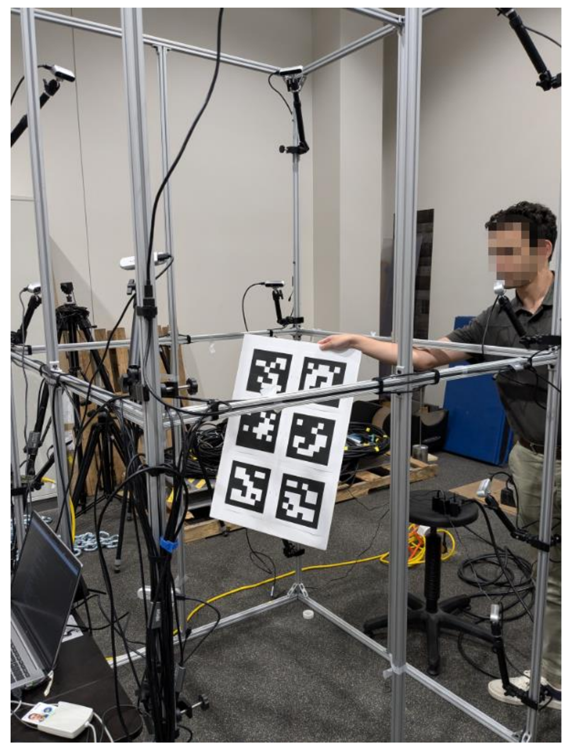
2. 3D Body Shape Manikins for Scan Performance Testing

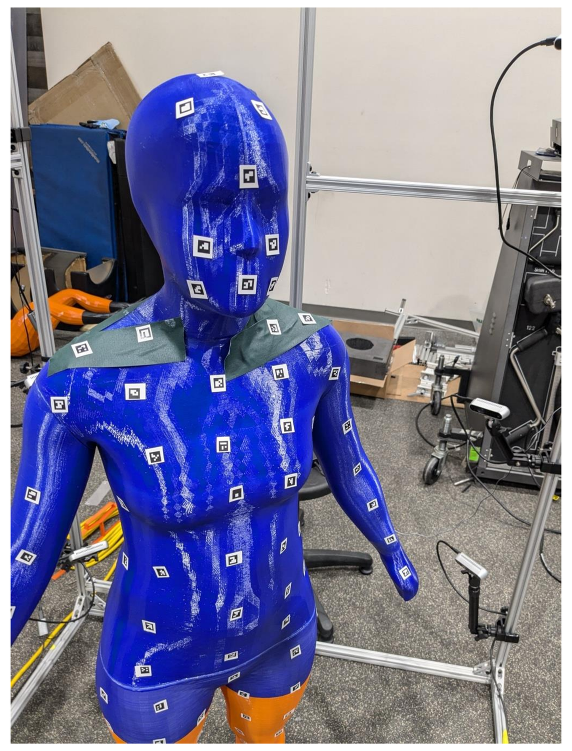
- The scan system performance was tested using manikins closely approximating the pre- and in-flight body shape and size changes.
- On flight day 15 in the ISS, stature increases by up to 3% and calf circumference decreases by up to 10% from pre-flight. A similar trend was observed for other body segment heights and circumferences.
- In–flight 3D body shape changes were predicted by anthropometry measurements and projected onto a 1st percentile female and 99th percentile male body shape.
- Manikins were fabricated by 3D printing.



3. Software and New Calibration Technique Development

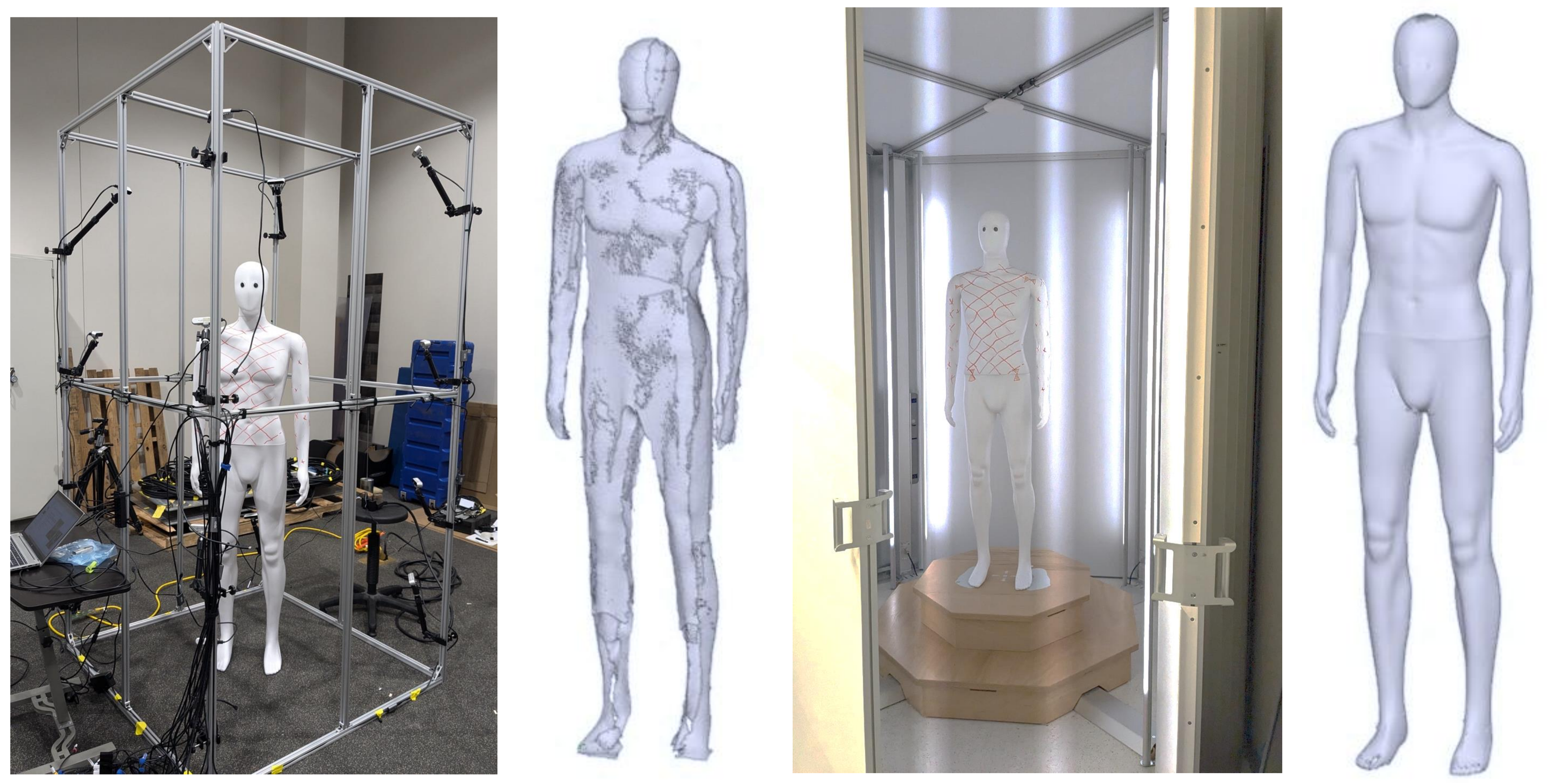
- System calibration is a time-consuming process for 3D scanning, specifically to transform the scan data from the camera-centric coordinate system to a global coordinate system.
- New methods based on a QR code-based system were developed and tested, which is commonly used in augmented reality
- The computer vision system identified the unique identifier and corners of the markers from the captured image, which estimated transformation matrices for relative sensor positions.



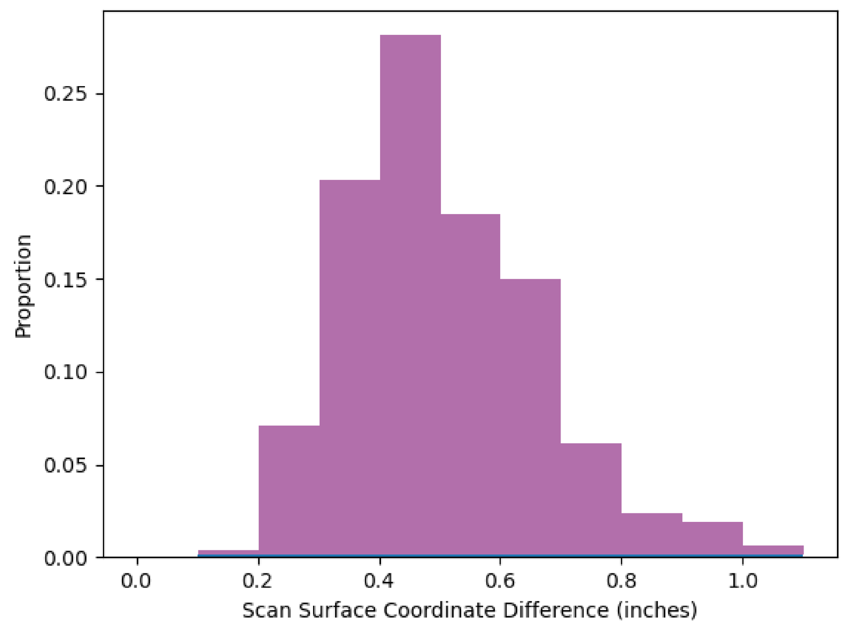


4. Scan Performance Assessment

- The generic manikin was scanned by the newly developed scanner and reference scanner (Human Solutions Vitus).
- The scan outcomes were overall comparable. However, the new scanner showed holes, artifacts, and noise especially at the hands, legs, and feet.



- The linear distances between surface points were 0.5 inches on average, with 95% of the differences below 0.8 inches (upper and lower torso segments only).
- The consistency in anthropometry measurements was assessed by standard technique that JSC-ABF has been using for NASA crew and test subjects.
- The extracted measurements showed differences ranging between -0.2 and 0.8 inches.



	New Scanner	Reference Scanner	Difference
Stature	74.5"	74.1"	0.4"
Chin Height	66.0"	65.9"	0.1"
Suprastenale Height	62.0"	61.8"	0.2"
Acromial Height	61.5"	61.4"	0.1"
Knee Height	22.1"	22.2"	-0.1"
Crotch Height	34.0"	34.2	-0.2"
Inter-Scye Breadth	14.2"	14.1"	0.1"
Chest Depth	9.1"	9.2"	-0.1"
Abdominal Extension	7.6"	7.8"	-0.2"
Chest Circumference	37.8"	37.6"	0.2"
Waist Circumference	32.5"	31.7"	0.8"
Thigh Circumference	6.8"	6.7"	0.1"
Calf Circumference	14.9"	14.6"	0.3"

Conclusion

- This work proved the feasibility of custom designed 3D body scanner development optimized for space vehicle and habitat environments.
- With a further increase in technology readiness level, the system can mature for deployment and operation.
- The obtained data can improve human-system integration and mitigate some crew health issues.

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