PREDICTIVE KINEMATIC MODELING OF REACHING TASKS WITHIN A SPACESUIT

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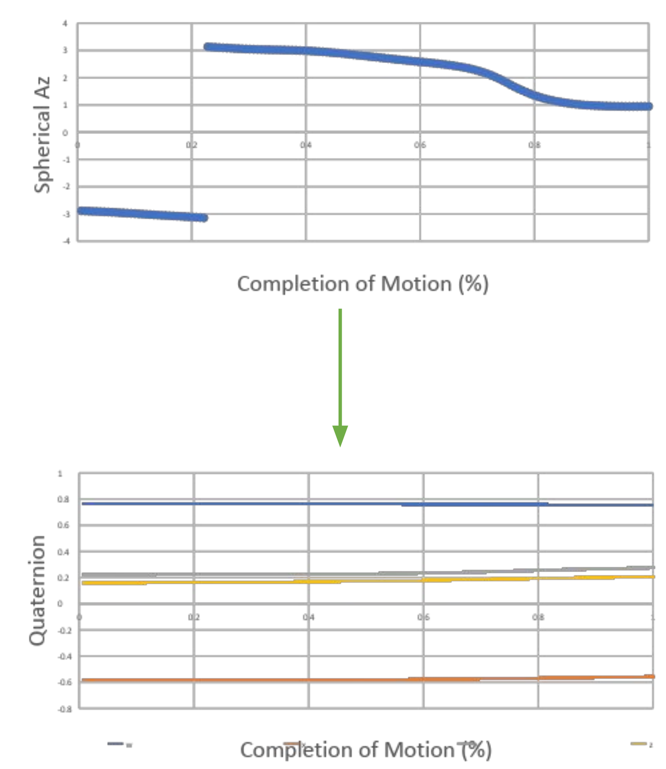
Introduction

Motions while wearing a spacesuit show unique patterns compared to unsuited human motions. Understanding the characteristic patterns is crucial for the design and operation of a spacesuit. This work will support an overarching goal of NASA's Anthropometry and Biomechanics Facility (ABF) to build a generative spacesuit motion database. This work specifically aimed at building and testing various modeling techniques, namely, using B-spline basis functions to model tangential hand velocity, quaternions for modeling hand orientation and location, and testing a spherical "quadrangular" interpolation of rotors with a cubic spline to interpolate rotation time-series.

Through this work, NASA's future spacesuit motion database will be able to not only categorize, search, and retrieve previously collected motion data efficiently, but also predict new motions which do not exist in the collected data.

Coordinate System Progression

Spherical coordinates were shown to be much more beneficial than Cartesian coordinates. However, we observed gaps due to sign flipping and decided to convert to using quaternions, which have the potential to also serve as a general and powerful rotation operator.



Methodology

Modeling Steps:

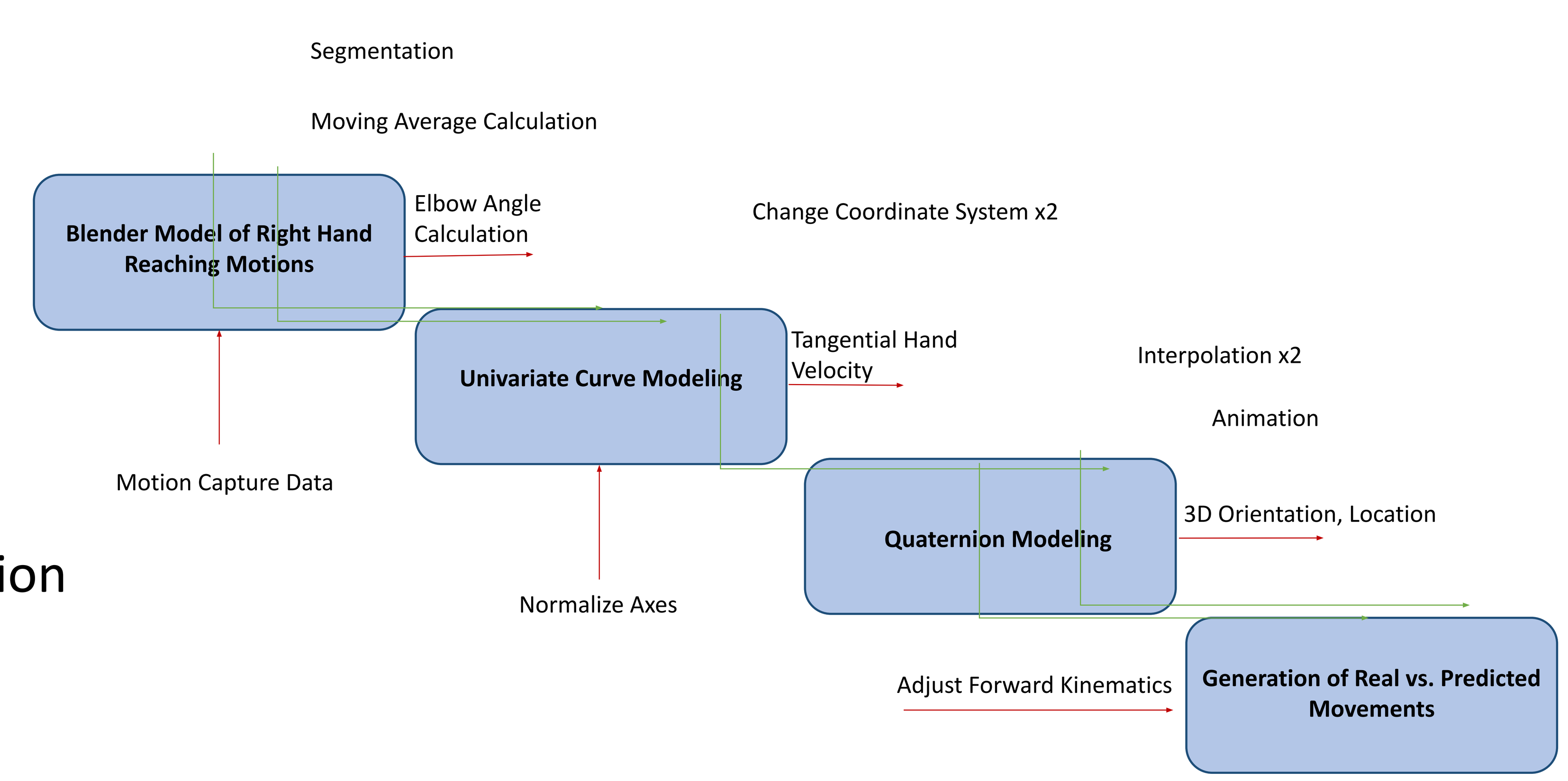
1) Motion Segmentation

2) Modeling Tangential Velocity with B-Splines

3) Coordinate System Progression
   - Cartesian
   - Spherical
   - Quaternions

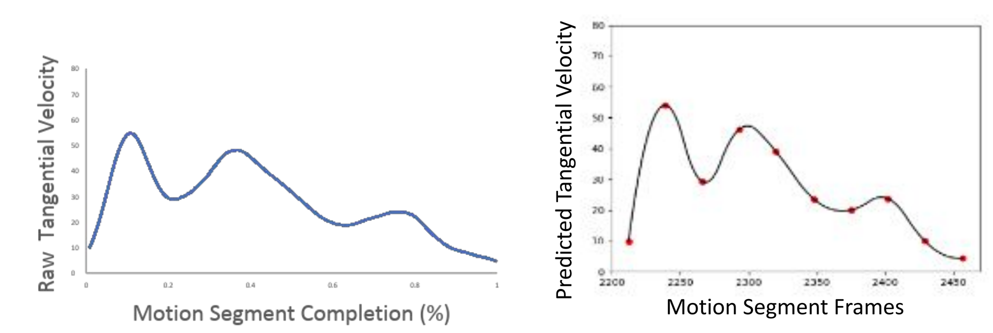
4) Modeling 3D Orientation and Location with Quaternions
   - *Slerp* function
   - *Squad* function

5) Generate Real vs. Predicted Movements



Tangential Hand Velocity Models

While polynomial curve-fitting is accurate for small datasets, it does not retain the same accuracy for large datasets, especially considering that some motion segments had 300+ points. Thus, it was decided to test B-spline basis functions to model each motion segment's combined x, y, and z tangential velocity. Since the many small perturbations that often accompany human motion are unnecessary for predicting a general curve, a moving average of 10 frames of hand distance before and after one particular frame was calculated, normalized, and graphed for all 34 motion segments. Then, in Blender's Python interface, the same calculation was run, and the combined tangential velocity was predicted using 10 control points for the B-spline function.

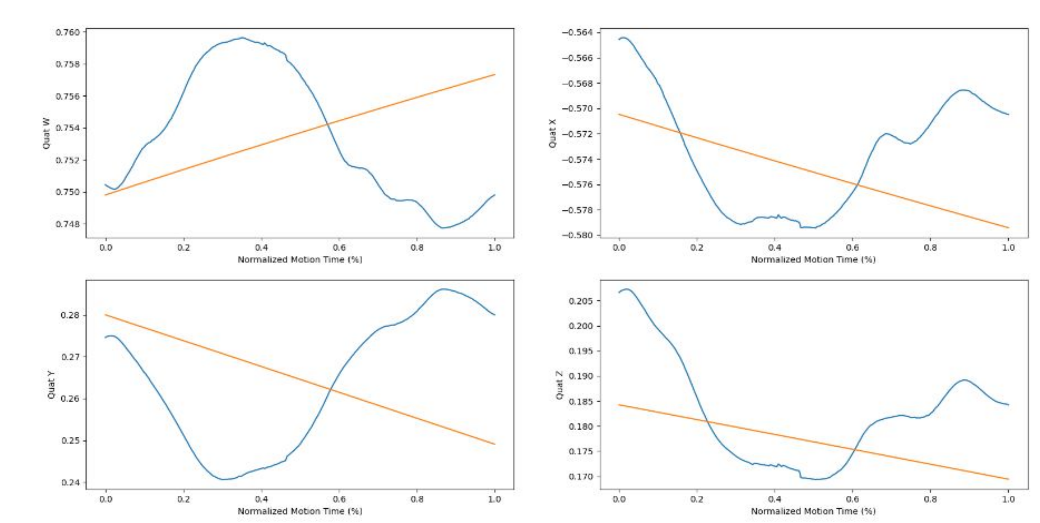


Quaternion Interpolation Results

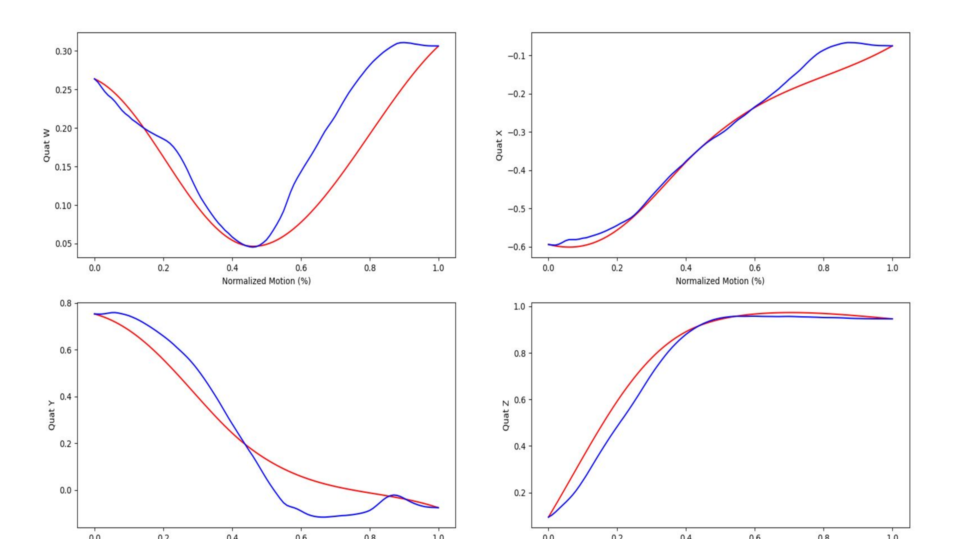
We first tested a spherical linear interpolation of quaternions (*Slerp).* In this interpolation of a rotation, the shortest path between two unit quaternions is found and can be projected onto the unit sphere as the great arc visualizing rotation matrices. This function is defined by:

$$slerp(\hat{q}_1, \hat{q}_2, t) = \hat{q}_1 . (\hat{q}_1^* . \hat{q}_2)^t .$$

and $(\hat{q}_1^* . \hat{q}_2)$ = $\cos\alpha + \hat{v}\sin\alpha$, where α is the angle between $\hat{q}_1$ and $\hat{q}_2$.
However, we found that while some motion segments could be interpolated well through this method, the majority of motion segments did not follow this linear interpolation.

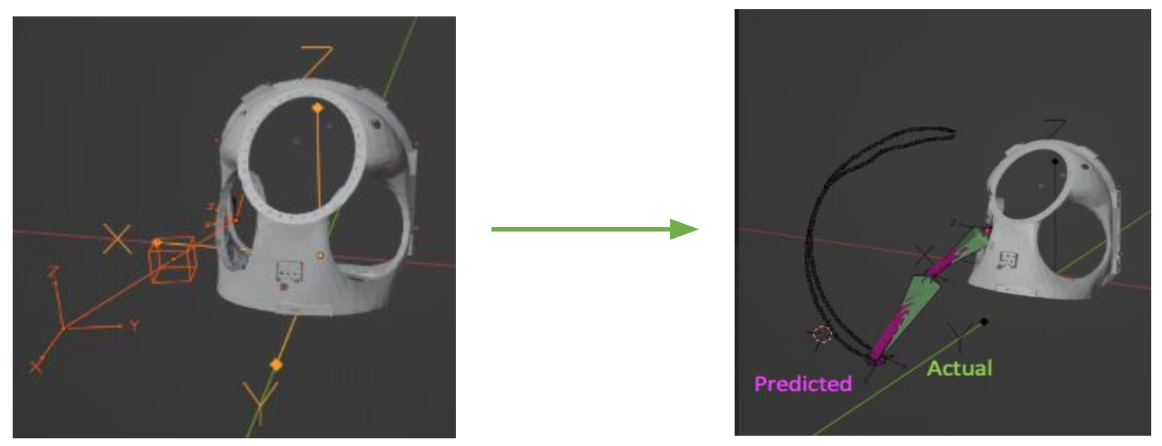


We then tested out a spherical "quadrangular" interpolation (*Squad).* This interpolation is similar to *Slerp,* except that we now produce a cubic spline interpolation due to a third, intermediate control point. Additionally, we improved the forward kinematics code, which allowed us to start at the hand and extend based on the elbow angle to connect the shoulder, leading us to improved orientation and distance accuracy.

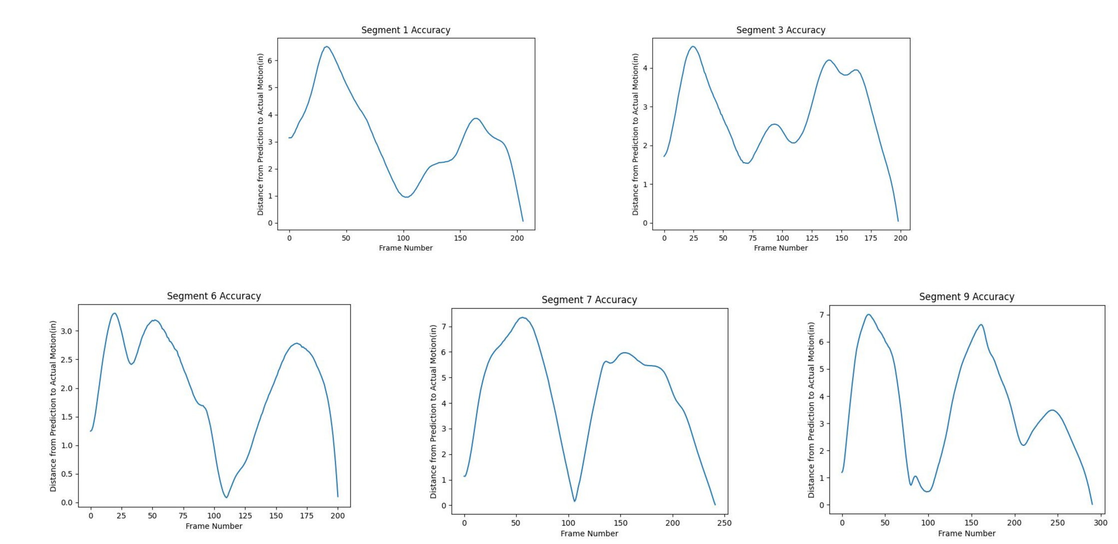


Predicted Motion Accuracy Results

After mathematically generating predicted reaching motions, we built tracking animations in Blender to display a visual representation of the comparison between reaching trajectories and bone segment paths.



Additionally, we determined accuracy by calculating the distance between real and predicted reaching trajectories for every frame of the motion segment. We selected five random motion segments to do this for and generated graphs of the accuracy.



Discussion and Future Work

In sum, we determined a way to statistically predict a variety of suited reaching motions using combined mathematical models. In terms of our accuracy, it is believed that the wave-like patterns were primarily caused by time phase differences. During certain parts of a reaching motion, either the real or predicted arm segment would accelerate, but both did not experience this at the same time. In addition, during the final stages of this work, we observed the issue of quaternion sign flipping. As with spherical coordinates, this can be resolved manually, and in the future, we hope to fix this. Overall, using this framework to build upon, our aim is to be able to predict even more complex motions, in order to work toward the ABF's goal of a generative spacesuit motion database.

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Characterization of Astronaut Movement Approaches for a Suited Object Pick-Up Task

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Introduction

It is known that astronauts take different movement approaches to performing functional tasks. This may be caused by a variety of factors, which include but are not limited to, spacesuit fit, experience level, and anthropometric differences. However, understanding how certain anthropometries will impact the efficiency of functional movement tasks remains difficult, as there is still a lack of precise knowledge of how humans move within a spacesuit. This project focuses on the Exploration Extravehicular Mobility Unit (xEMU) spacesuit testing done at NASA's Active Response Gravity Offload System (ARGOS). The overall goal was to develop a quantifiable, classification schema for understanding these movement differences within the context of the object pick-up task, a functional task shown to have high variability across subjects. Identified movement strategies for the object pick-up task were then modeled in Blender in combination with three anthropometric percentiles, and movement efficiency was determined in the context of hand-ground distance.

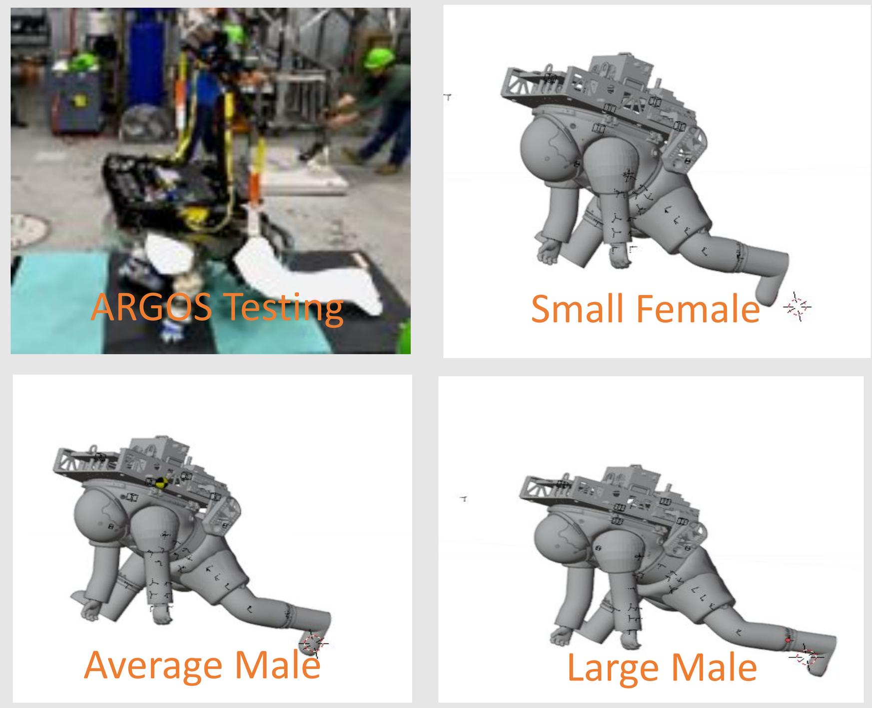
Methods

9 participants (7 males, 2 females) performed 30 different functional movement tasks, such as treadmill walking, squatting, using various tools, and kneeling. All available ARGOS Go-Pro video files from this xEMU suit testing cycle were placed into a subject-specific folder and labeled by tool or functional task. Qualitative observations regarding how each subject performed each task were noted and documented within a spreadsheet. The Object Pick-Up task was chosen as the focus, due to large amounts of observed variability between subjects. In addition, anthropometric differences were taken into account. In terms of body shape and stature, we picked a representative small female, an average male, and a large male.

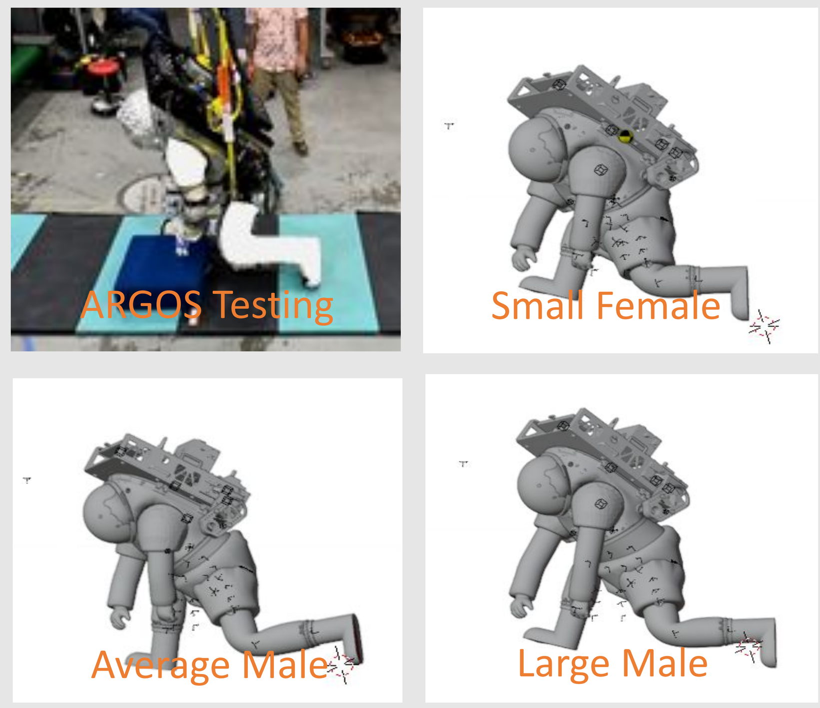
3 Main Techniques for Object Pick-Up

- Large waist flexion, less waist rotation, outward front knee rotation, front foot pronation, back foot supination
- Less waist flexion and rotation, minimal foot pronation and supination, large knee flexion for both front/back knees
- Large waist rotation, outward front knee rotation, largely straight back leg, back foot rotates inward

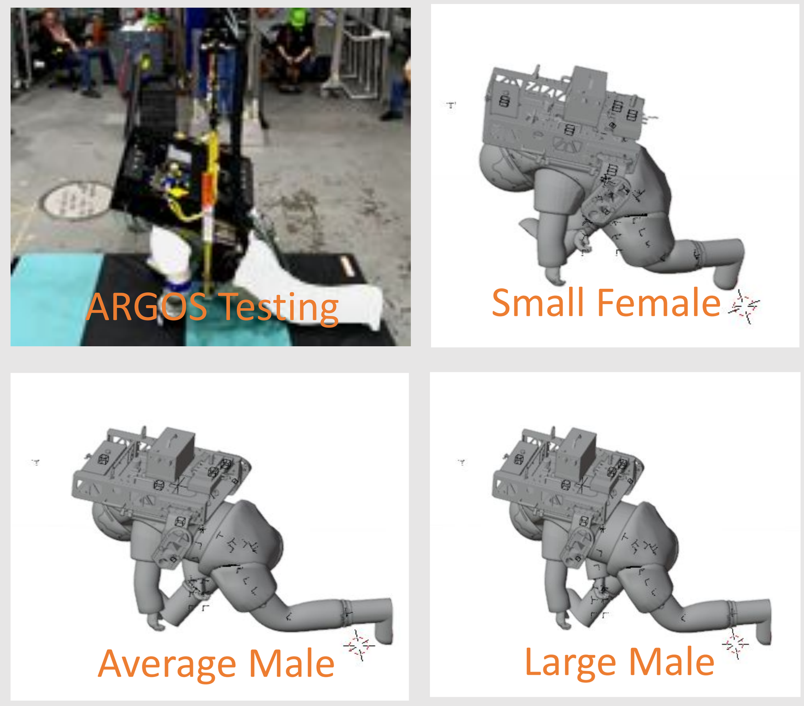
Blender Modeling



Technique 1

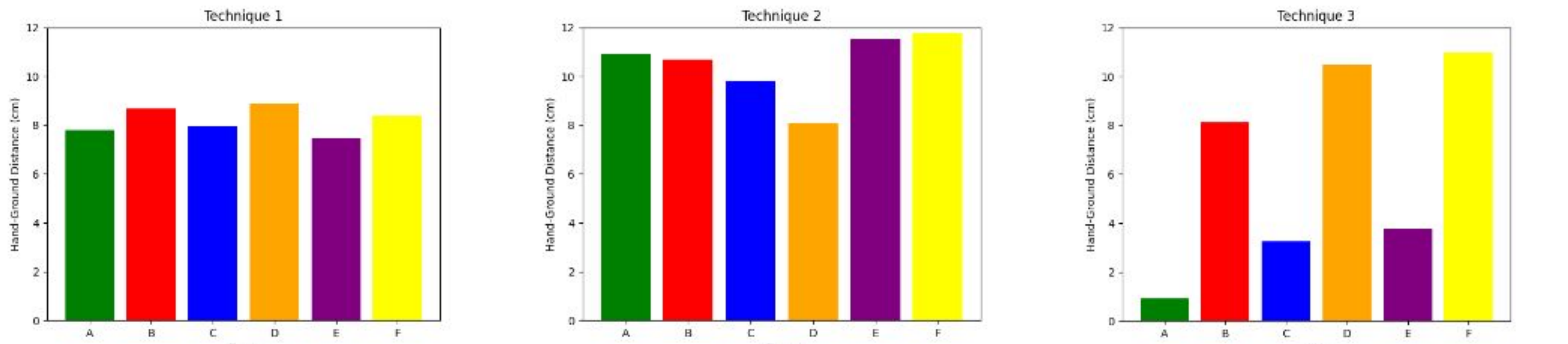


Technique 2



Technique 3

Kinematic Results



These charts show left and right hand-ground distance for the 3 techniques and each anthropometric group. A = left hand-ground distance for small female, B = right hand-ground distance for small female, C = left hand-ground distance for average male, D = right hand-ground distance for average male, and the same pattern holds for E and F. For hand-ground distance, "ground" was defined as the minimum z-value coordinate across both boots, and "hand" was defined as the minimum z-value coordinate of both gloves.

Kinematic Calculations

Subject	Avg. Waist Flexion Angle (deg)	Avg. Waist Rotation Angle (deg)	Avg. Left Hip Flexion Angle (deg)	Avg. Right Hip Flexion Angle (deg)	Technique Identified
1	7	17.7	61.2	20.5	2
2	36.8	13.6	65.6	35.1	1
3	37.4	6.7	67.8	22.9	1
4	34.4	14.5	28.4	76.6	1
5	46.4	38.5	75.9	97.2	1
6	19.1	14.5	35.1	56.6	2
7	14.3	10.7	60.4	27.3	3
8	28.3	18.6	27.5	72.1	1
9	17.2	16.2	80.8	48.1	2

Discussion and Future Work

Overall, these models show that a large amount of torso rotation may be a highly efficient strategy for allowing one hand to touch the ground, but not an optimal technique when attempting to touch both hands to the ground. For two-handed pick-ups, technique 1 appears to be the most optimal strategy, regardless of anthropometric differences. However, these findings may be applicable only to ARGOS due to offloading gimbal restrictions. In the future, we can apply these methods to make generalizations about suit fit and optimal training techniques to lower injury risks.

Eventually, we hope to compare movement strategies against spacesuit experience, as it is thought that more experienced users will employ more efficient techniques, despite perhaps being accustomed to certain strategies. We also aim to add 3D calculations for measuring joint rotations, particularly for the knee and ankle.

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A Preliminary Ergonomic Risk Assessment of Hand-Held xEVA Tools

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Introduction

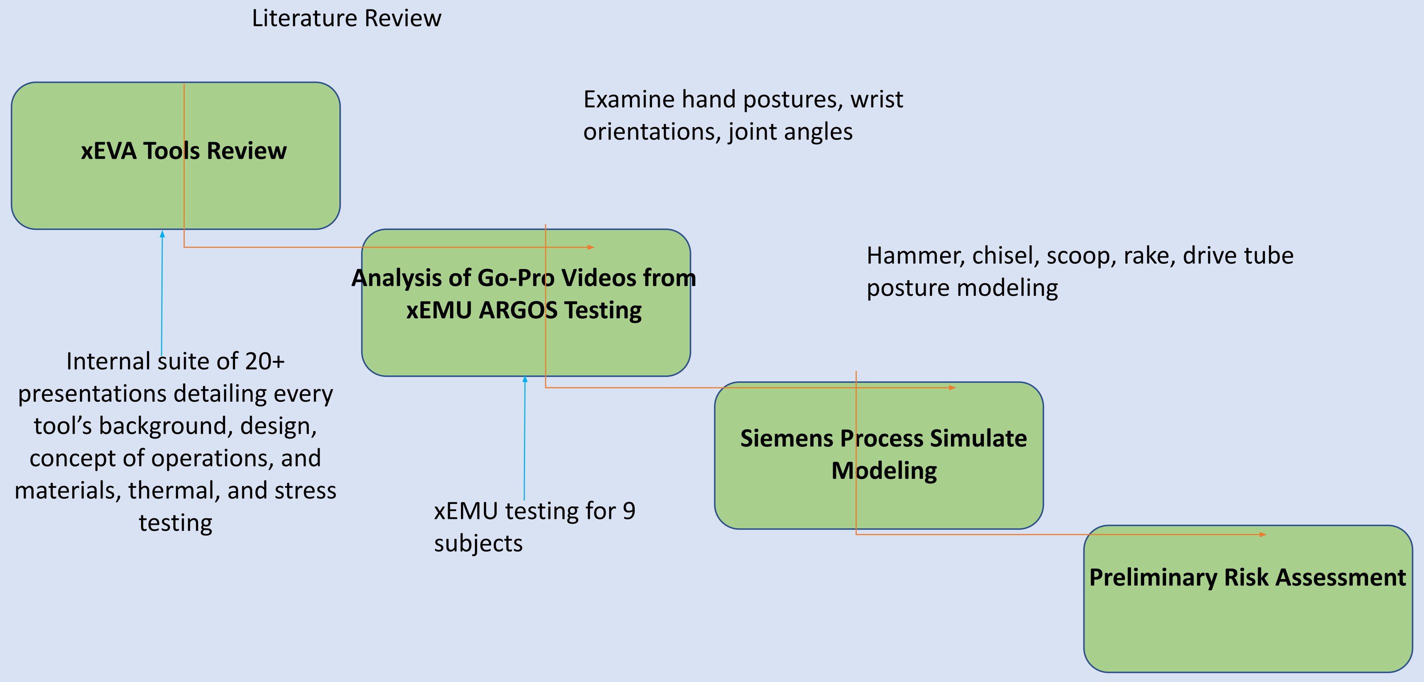
Through its Artemis Program, the National Aeronautics and Space Administration (NASA) plans to send humans back to the moon with the hope of facilitating future crewed missions to Mars. The crews will be comprised of diverse populations, and the current spacesuit, the Exploration Extravehicular Mobility Unit (xEMU), is required to accommodate individuals who fall within a 1st to 99th percentile range on a variety of critical dimensions. However, designers are usually limited to one size of a spacesuit prototype, which forces human performance issues, such as kinematic limitations, ergonomic concerns, and sizing problems, to be anticipated through other methods.

We focus on using virtual modeling to better understand critical Extra-Vehicular Activity (EVA) tasks in order to predict injury risks and to perform a preliminary risk assessment and data gathering effort to better understand xEMU hand exertions through typical lunar EVA tasks.

Background

Lunar EVAs introduce new ergonomic hand risks due to the variety of functional tasks needed (e.g. trenching, scooping). Furthermore, during Active Response Gravity Offload System (ARGOS) testing, xEMU test subjects reported that hand fatigue was common, especially while working with EVA tools. This drove us to look at the five most potentially fatiguing hand-held tool tasks and provide some early characterizations of hand postures.

Methods



Process Simulate Modeling

Hammer


Pre-Hammering Position


Post-Hammering Position

Chisel

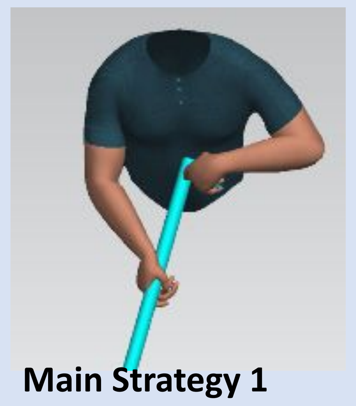

Observed Radial and Ulnar Deviation During Chisel Use

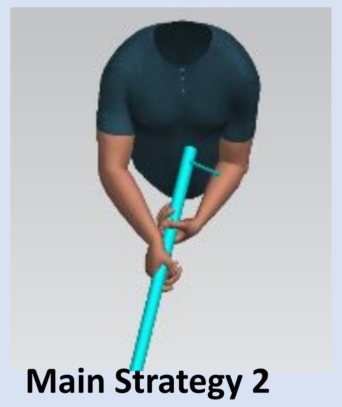
Scoop


Pre-Scooping Position

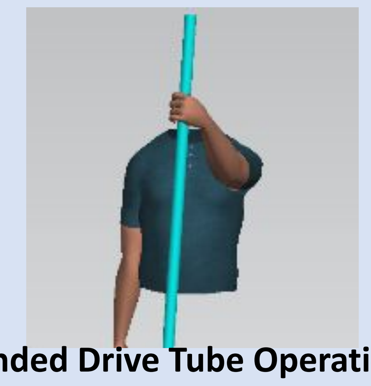

Post-Scooping Position

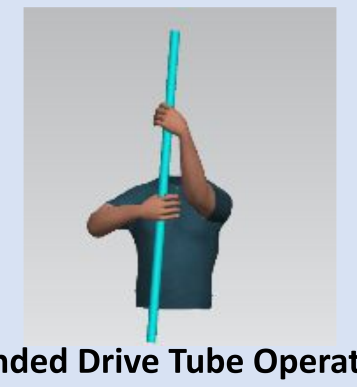
Rake


Main Strategy 1


Main Strategy 2

Drive Tube


One-Handed Drive Tube Operation


Two-Handed Drive Tube Operation

Preliminary Ergonomic Risk Assessment

A preliminary ergonomic analysis of the hammer, chisel, scoop, rake, and drive tube was conducted. Across these five tools, we observed a large potential for wrist strains, repetitive contact forces, and muscular fatigue.

Tool	Observed Ergonomic Risks
Hammer	• High possibility of arm and hand fatigue due to amount of repetitive contact forces • Strained wrist postures while hammering may lead to muscle fatigue
Chisel	• These wrist postures reduce static grip strength, which is exacerbated by limited glove mobility
Scoop	• Subjects held scoop handle at the very end and had difficulty obtaining samples • However, a longer handle increases the moment arm of the weight, leading to greater stability challenges
Rake	• Button and latch dimensions are unknown; astronauts might have the glove mobility and dexterity to press small buttons accurately • All subjects rake on one side of the body, which increases the risk of injury due to overusing the same muscles • Different grip postures were observed, resulting in differences in stability and hand exertion
Drive Tube	• Have yet to determine the amount of force needed to drive the tube into a frozen simulant and the amount of force to pull the tube out of the frozen simulant; high enough, repetitive forces may cause shoulder or hand injuries • Especially with overhead hand postures, we observed ulnar deviation, given that one cannot bring the elbow out easily

It should be noted that ergonomic analyses were also conducted for the remaining tools, but hand models were only built for the five aforementioned tools. Overall, this work will better help NASA to understand EVA injury risks and characterize hand exertions during suited EVA tool use.

Future Work

Future work for this project will include the following:

1. More quantitative assessments of hand loads using ergonomic and biomechanical models
2. Through video analysis, quantify duration, average duration, and frequency of different hand postures
3. Using wearable sensor instrumentation, quantify hand loads across various gloved hand postures and EVA-like handles

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