CREATING A SKIN STRAIN FIELD MAP WITH APPLICATION TO ADVANCED LOCOMOTION SPACESUIT DESIGN

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INTRODUCTION

An improved understanding of the deformation of the body's soft tissue during locomotion would enable quantitative design requirements for advanced spacesuits. A repeatable, quantitative technique for mapping the skin strain field on the human body in motion provides this understanding. The skin strain field map informs the design of a skintight spacesuit, called a mechanical counter pressure suit [1], whose fabric must stretch and rotate with the astronaut's skin to allow for maximum mobility.

METHODS

To measure the strain of the human skin *in vivo* during locomotion, the non-invasive strain measurement technique of Digital Image Correlation is applied to data sets gathered by a 3D laser scanner rather than by optical cameras [2]. In this pilot study, knee flexion from 0 to 90 degrees, for one subject, is used as the representative movement for human locomotion. The leg surface is marked with 156 position trackers that can be identified in the laser scanner's 3D virtual reconstructions of the leg surface. Each tracked point is separated by approximately 3 cm from adjacent points, and each triad of points defines a local surface reference frame with a longitudinal and a circumferential direction. Normal strains emanating out from each tracked point are estimated by comparing the initial separation of each pair of adjacent points to the deformed separation of each pair. Strain gage rosette equations transform these strains from extension/contraction along arbitrary axes to the normal and shear components of the orthogonal strain tensor, with respect to the longitudinal and circumferential axes. Eigenvalue analysis of this strain tensor provides information about the directions and magnitudes of principal strain and of minimum normal strain.

The goal of the analysis is to provide three types of strain information for all tracked body surface points: 1) the strain in the local longitudinal and circumferential directions, 2) the directions and magnitudes of purely normal strain, and 3) if they exist, the directions and magnitudes of purely shear strain. This information specifies in which directions and with what magnitudes an astronaut "second skin" pressure suit must stretch or contract at each location on the body surface.

RESULTS AND DISCUSSION

For the one subject in this pilot study, the largest stretch of the leg skin in the longitudinal direction occurs 3 cm to 9 cm below the patella; longitudinal normal strain magnitudes in this region range from 0.3 to 0.7 (Figure 1). The largest stretching in the circumferential direction occurs on the anterior surface 3 cm below the patella and on the medial surface of the mid-calf, with normal strain values of 0.6 and 0.5, respectively. Shear strain, or angular distortion of the skin, is near zero for most of the anterior and posterior surfaces of the leg.

Eigenvalue analysis transforms the orthogonal strain components into principal and minimum strain directions. The set of minimum normal strain directions suggests the "weave" direction of the tensile fibers of the spacesuit. Proper weave alignment will allow for maximum mobility and ease of locomotion, which are essential requirements for advanced spacesuit designs for future missions to the moon or Mars.

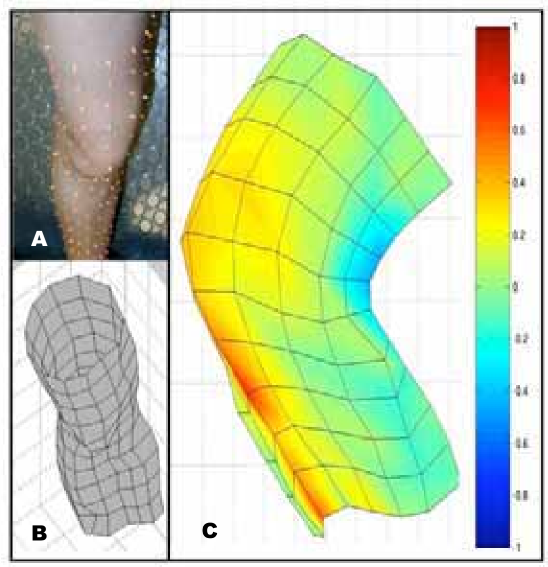

Figure 1: **A.** Raised position trackers covering the leg surface are identified in laser scans and serve as input for a virtual 3D model of the leg. **B.** Leg reconstruction in initial state, from upper thigh to mid calf, using only the positions of the tracked points. **C.** Leg reconstruction with 90-degree knee flexion angle, with the magnitude of skin's longitudinal strain overlaid in color.

REFERENCES

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ACKNOWLEDGEMENTS

The authors wish to thank Natick Soldier Systems Center for the use of their whole-body laser scanner. Financial support provided by NASA Institute for Advanced Concepts and the National Science Foundation Graduate Research Fellowship.