Human-Robotic Symbiosis to Enable Future Planetary Extravehicular Activity

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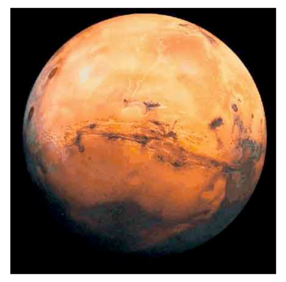
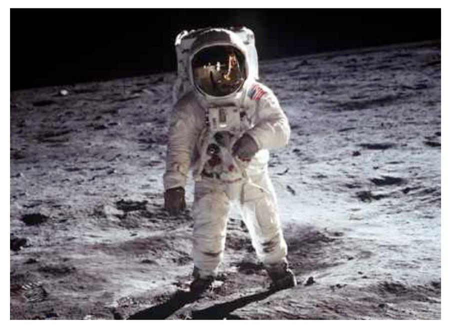
INTRODUCTION



- Government space agencies worldwide aim to return humans to the Moon by 2020 and eventually send humans to Mars
- Mobility, don/doffability and low mass are high priorities for a feasible, next generation planetary suit



- Traditional suit architectures each compromise: mobility, weight, fabrication and support logistics, costs, and don/doffability
- New suit architectures *must* be developed to enable astronauts to explore these environments

MORPHING UPPER TORSO CONCEPT

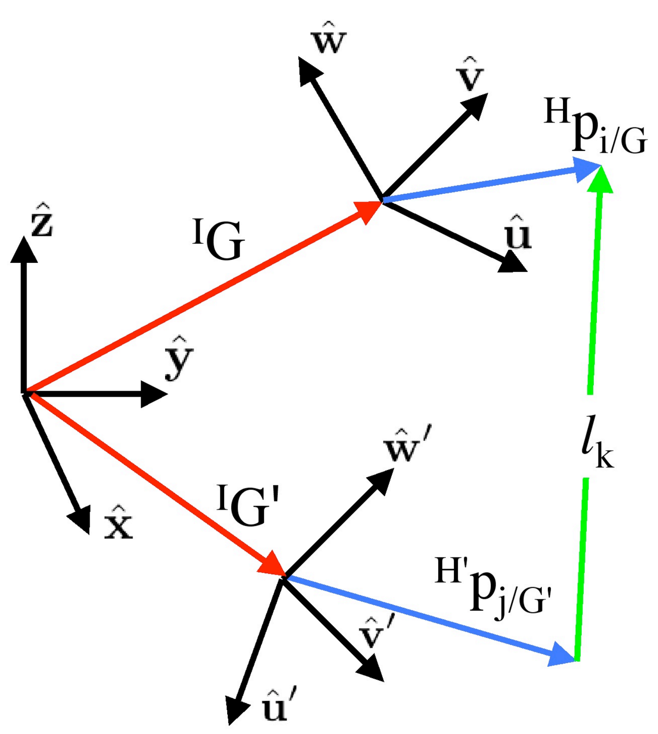
- Incorporate robotics directly into the suit, creating a human-robotic symbiosis which can solve many of these suit-design challenges
- Helmet ring, waist ring and two shoulder rings make up a system of four interconnected parallel manipulators
- Advantages of parallel manipulators (high accuracy, high stiffness, high load-bearing capability) map extremely well to suit mobility requirements
- Allows dynamic control of position and orientation of each ring
- Enables modification of critical sizing dimensions as well as task-specific orientations

METHODOLOGY

ANALYTICAL MODELS

- Pose (position and orientation) of each ring is:

$$\mathbf{x} = \begin{bmatrix} {}^I\mathbf{G} \\ \Theta \end{bmatrix} = \begin{bmatrix} G_x \\ G_y \\ G_z \\ \alpha \\ \beta \\ \gamma \end{bmatrix}$$



- The position vector of each node is defined as:

$${}^I\mathbf{p}_{i/G} = {}^I R_H \, {}^H\mathbf{p}_{i/G}$$

- A rotation matrix is constructed from the Euler angles as shown:

$${}^I R_H = \begin{bmatrix} c\beta c\gamma & s\alpha s\beta c\gamma - c\alpha s\gamma & c\alpha s\beta c\gamma + s\alpha s\gamma \\ c\beta s\gamma & s\alpha s\beta s\gamma + c\alpha c\gamma & c\alpha s\beta s\gamma - s\alpha c\gamma \\ -s\beta & c\beta s\alpha & c\beta c\alpha \end{bmatrix}$$

- The loop vector equations are:

$$({}^I\mathbf{G} + {}^I\mathbf{p}_{i/G}) - ({}^I\mathbf{G}' + {}^I\mathbf{p}_{j/G'}) = l_k \hat{\mathbf{s}}_k$$

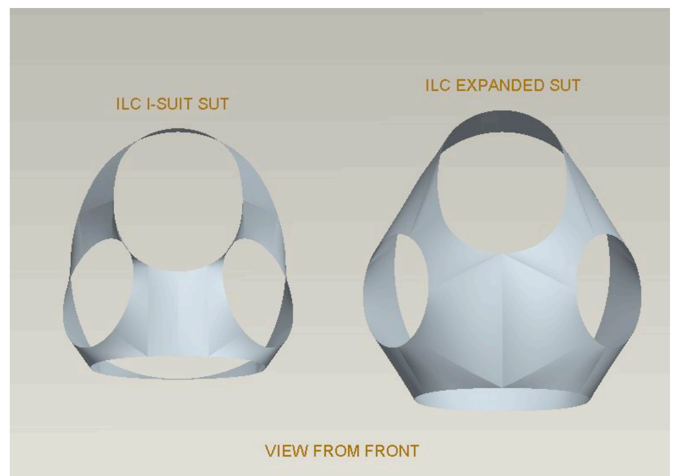
- The Jacobian Matrix, relating actuated link velocities to the velocities of the rings is:

$$\hat{\mathbf{s}}_k \cdot (\mathbf{v}_G - \mathbf{v}_{G'}) + (\mathbf{p}_{i/G} \times \hat{\mathbf{s}}_k) \cdot \Omega - (\mathbf{p}_{j/G'} \times \hat{\mathbf{s}}_k) \cdot \Omega' = \dot{l}_k$$

$$J\dot{\mathbf{x}} = \dot{\mathbf{q}}$$

EXPERIMENTAL MODEL

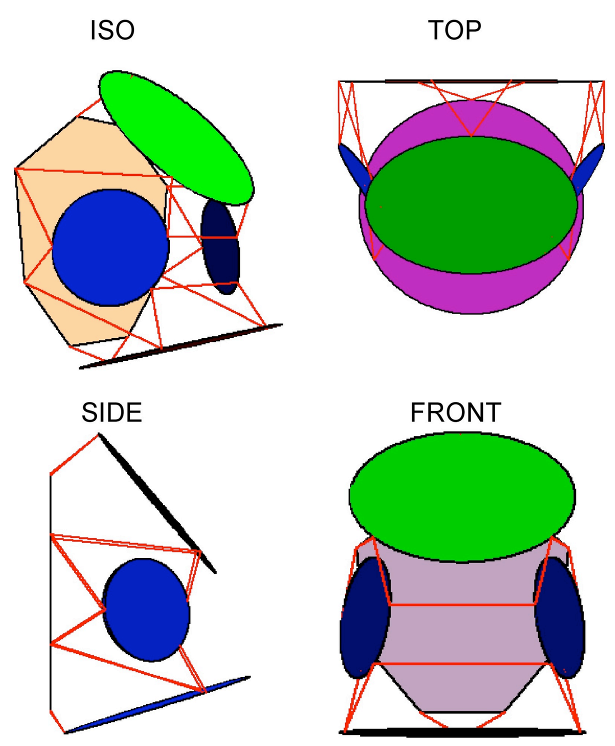
- Full scale experimental model designed and fabricated in cooperation with ILC Dover



- Torso is based on the I-Suit, a prototype planetary spacesuit
- I-Suit Dimensions expanded to make very large torso, which is easy to ingress/egress
- Manually adjustable linkages
- Used in conjunction with analytical models to demonstrate feasibility and advantages of morphing concept

RESULTS

- The Inverse Kinematics (IK) of the system (calculating the link lengths given the pose of the rings), have been modeled and solved analytically
- The Forward Kinematics, opposite to the IK, have been solved numerically (model shown on right)
- The experimental model has demonstrated that the Morphing Upper Torso can be reconfigured, prior to pressurization, to any required suit dimensions, as shown below



- The Jacobian has been derived analytically, enabling dynamic tracking of trajectories as discussed in future work
- The combination of analytical and experimental models have proven the feasibility of the system

CONCLUSIONS

- The Morphing Upper Torso is a feasible suit architecture which may solve many of the challenges facing spacesuit engineers
- Given incremental evolution of technology, this human-robotic symbiosis can be implemented in four progressive modes, each mode providing enhanced capabilities:
  - **Passive Static:** Links are lengthened during donning and doffing, thus greatly increasing don/doff ease and efficiency, and then manually reset to individual dimensions prior to pressurization. This enables one suit to fit perfectly to multiple users.
  - **Active Pressurized:** Links can be adjusted after pressurization, providing adjustment for body shape changes.
  - **Active Reconfigurable:** The suit can be set to specific configurations for each task such as walking, hammering, or sitting.
  - **Active Adaptive:** The suit continually adjusts to wearer's body kinematics in real time.
- Many challenges still remain: better actuator technology is required, mass and power must be minimized, much more experimental testing is needed
- This work leads towards a fully augmented pressure suit, which will significantly increase the astronaut's capabilities and the efficiency of future planetary EVA

FUTURE WORK

- Integration into MX-2, including suit-mounted robotic arm for enhanced human-robotic symbiosis

- Motion capture study is underway to obtain ring trajectories
- Controller design is underway to track these trajectories

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ACKNOWLEDGMENTS

Special thanks to everyone at the SSL, past and present, especially to my team of undergraduate students Ali Husain, Adam Mirvis, and Heather Bradshaw. Funding for this work is from ILC Dover and the NASA Institute for Dexterous Space Robotics.