SmartSuit for ExtraVehicular Activity (EVA) 
Current Challenges and Spacesuit Technology Development to Enable Future Planetary Exploration Missions

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ExtraVehicular Activity (EVA)

• Extravehicular activity (EVA) is any activity performed by a pressure-suited crewmember in unpressurized space environment

• Why do we want to send humans on EVA?
  - Limitations on remote control
  - Limits on perception, dexterity, mobility
  - Time delays

• EVAs have facilitated:
  - Repair of satellites, including the Hubble Space Telescope
  - Construction of the International Space Station (ISS)
  - Exploration of the Moon

Credits: ESA/NASA
Hoffman and Musgrave repairing the HST, Dec 1993
Spacesuit – “Tiniest” Spacecraft

- Smallest aircraft capable of sustaining human life
- What do you need to survive in space?
  - Oxygen
  - Carbon dioxide removal
  - Pressure
  - Thermal control
  - Water
  - Food
  - Waste collection
  - Power
  - Communication
  - Radiation protection

Diagram of Apollo 14 EMU Suit
First EVAs

- Alexei Leonov perform the first spacewalk on March 18th 1965
  - Zvesda Berkut suit, connected by a 15.5m tether, 12 min of EVA
  - The suit stiffening force him to reduce the pressure to get back into the airlock
  - Heat expenditure exceeded suit capacity
    - Sweat, visor, body temp
- First American spacewalk:
  - Ed White – 21 min on June 3rd 1965 (Gemini IV)
  - Tethered life support, mobility issues
- Lessons learned: mobility, thermal control, training (pool training, equipment)
Apollo EVA

• Arguable the most memorable EVAs ever performed
  - Critical for Apollo mission success
• 15 Lunar EVAs by 12 men on 6 missions
• Returned 382 kg of lunar samples

Aldrin, Apollo 11 (ILC A7L suit, HS-6 portable life support system)
Apollo Suits

- Function: IVA & EVA
- **Customized garments!!!!!**
- Operating pressure: 3.7 psi (25.5 KPa)
- Portable life support systems up to 7 hours
- Liquid cooling garment for thermal control
- Convolute joints for mobility

Figure 6.7.12 in U. S. Spacesuits. 2011 Kenneth S. Thomas. ISBN 978-1441995650
Extravehicular Mobility Unit

• Spacesuit pressurized to 29.6 KPa (4.3 psi), 100% oxygen and 14 different layers

• Three main components:
  - Liquid cooling and ventilation garment (LCVG)
    • Maintain body temperature
    • Proper air circulation
  - The Spacesuit Assembly (SSA)
    • Hard Upper Torso (HUT): pivoted and planar version
    • Arm and glove assembly
    • Lower torso assembly: waist, lower torso, legs and feet
  - Life Support System (LSS)
    • Backpack

Image courtesy of “Human Spaceflight”
EVA-related Injuries

Tiger Team, 2003

Tiger Team, 2003

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Dervay, NASA JSC

Strauss, 2004

Jones, 2006
EVA is a Challenging Activity

- EVA is one of the most dangerous parts of a space mission
- Highly pressurized spacesuits:
  - Low mobility, high strength required, fatigue
  - Injuries and discomfort
- Current EMU (4.3 psi), 100% oxygen
  - Only microgravity environment

- Risks are significant
  - Fatigue and exhaustion due to poor mobility
  - Suit injuries
  - Equipment failure
  - Decompression sickness
  - Thermal stress
  - Radiation exposure
SmartSuit – Soft-robotics, self-healing & Smart Sensing

Hybrid, intelligent, and highly mobile SmartSuit for EVA on a planetary surface (e.g. Mars or Moon)

1. **Full body soft-robotic layer** within the gas-pressurized suit to provide high mobility
   - Layer also provides mechanical counterpressure, allowing a reduction in gas-operating pressure, further increasing mobility

2. **Outer layer made of stretchable self-healing skin**

3. **Stretchable, integrated, and transparent sensors embedded in the membrane**
   - Collects and displays environment and skin membrane structural health data
Introducing Soft-Robotics in the Spacesuit

• Current exoskeletons are composed of hard robotic elements

• Use of soft-robotic technology with highly compliant robotic elements to facilitate human-spacesuit interactions

• Soft-robotic layer to counteract spacesuit-induced torques on human joints
  - Use of musculoskeletal dynamics to investigate its effect on human performance

Zhao, 2015
Biomechanics Approach

- Soft-robotic elements to “counteract” the effects of the spacesuit
  - Spacesuit is modeled as external torques applied to human joints
  - Based on experimental data
  - Compilation of a torque-joint database on spacesuit joints

Schmidt, 2001
Valish, 2012
Spacesuit impact on joint torques
Approach: Comprehensive human-spacesuit interaction analysis

• Novel joint-torque relationships when using soft-robotic layer
  - e.g. hip, knee, ankle, grasping motions

• Biomechanical analysis
  - Human joint torques, muscle strength, range of motion

• New operational constraints in a mission to Mars
  - Requirements for energy expenditures, consumables

• Some level of Mechanical Counterpressure
  - Less gas to pressurize the suit ➔ increase in mobility
  - Improvement in pre-breathing times during EVA preparation
Stretchable Self-Healing Skin

- In situ damage to a spacesuit is a mission critical, life-threatening event
- We propose a self-healing formulation
  - Low-cost polyurethane elastomer composite of healing material
  - Rapidly healing in case of emergency & structural stable membrane

Approach: explore healable foam composites and the mechanical properties of different formulations in the context of SmartSuit
- Temperature compatibility, outgassing, fatigue life of composites, bacterial collection
Smart Sensing – Stretchable optical guidelights

• Stretchable optoelectronics will be embedded into the self-healing membrane to monitor spacesuit stress
  - Collects strain information providing feedback to the user about potential failure, what EVA operations are more strenuous, membrane structural health

• Measure the change in power output through the lightguide based on external conditions (i.e. pressure)

Approach: investigate sensor architectures and display technology
• Design principles for SmartSuit, including rationales for material, sensor, and display technology selection
Networks of stretchable lightguides (“Optical Lace”) for Position and Force Sensing

*Xu et al. (in review)
SmartSuit – Increase Human Performance on Several Fronts

• Increase in mobility
  - Reduced metabolic costs and pre-breathing times

• Increase reparability and usability

• Reduction of EVA duration
  - Reduced pre-breathing protocols, enhance dexterity, provides structural information and data from the environment

• Technical Approach
  - Human-spacesuit interaction analysis to quantify improved human factors requirements
    • Novel joint-torque relationships, biomechanical analysis, strength, range of motion, metabolic cost and impact on consumables, etc
  - Analyze materials and sensor architectures
  - Outline the Smartsuit system design and concept of operations, including rationales for materials, sensor, and display technology selection
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