X-ARM:

A NOVEL ARM EXOSKELETON COMBINED WITH EXTENDED REALITIES TO TRAIN FUTURE ASTRONAUTS

ASTRA 2023 (18-20 October, Leiden - NL)

spaceapplications SERVICES

SINCE 1987

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CONTENT

spaceapplications SERVICES

3 SHORT COMPANY PRESENTATION

- Founded in 1987
- Aerospace engineering and service
- ~100 employees
- ISO 9100 certified (flight activities)
- Markets: **Space**, Health, Environment, Security

Commercial Service in ISS: Ice Cubes

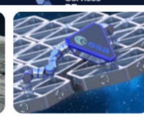
Human **spaceflight training**

Operation

ESA projects:
- Space robotics,
- Countermeasure devices,
- VR/AR,
- On-Orbit Servicing, In Situ Resources Utilization, Ground control centers…

EC / H2020: Space Robotics Technologies Cluster, terrestrial applications…


ESA ALCHEMIST (ISRU)


ESA MIRROR multi-arm robot


Ice Cubes Service


LUVMI-X lunar rover

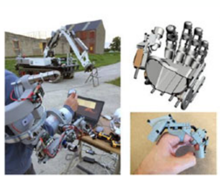
4 INTRODUCTION

Context

- A growing number of space travellers is anticipated in the next decades
- The outer space is one of the most hazardous environments for human beings
- Conventional tools to train astronauts combine real-size mock-ups, parabolic flights, air bearing floors, gravity compensation devices, and neutral buoyancy facilities, among many others.
- These tools are not well adapted to host a large number of individuals

Space Applications has +13 years of experience designing exoskeletons and countermeasure devices


EXOSTATION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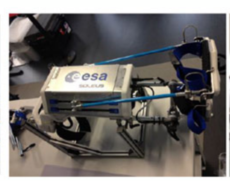
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ATHLETIC

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INTRODUCTION

Context

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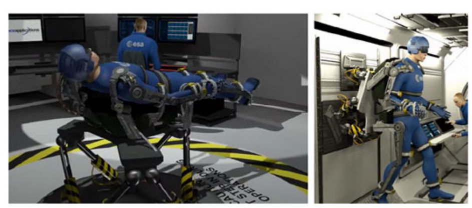
INTRODUCTION

Objective

- The <u>ultimate objective</u> is to create a training setup that, compared to conventional tools, offers:
  - higher immersion and safety
  - higher flexibility and customization
  - higher scalability and smaller footprint
  - less supervision and maintenance
- Our vision is to achieve this through <u>perception deception</u>, or combination of multimodal stimuli:
  - Force feedback (Exoskeleton)
  - Visual and aural (Virtual Reality Headset)
  - Vestibular platform



ESA FITS concept

X-ARM is a <u>technology demonstrator</u> that shows how custom BLDC motors, an improved structural design, a new ergonomic interface and multiple software improvements can make a force-feedback training exoskeleton more <u>robust</u>, <u>transparent</u> and <u>comfortable</u> compared to previous iterations

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INTRODUCTION

Use Cases

- Extra Vehicular Activities (EVA)
  - Motivated by ISS and Lunar Gateway missions
- Planet exploration
  - Motivated by ARTEMIS mission

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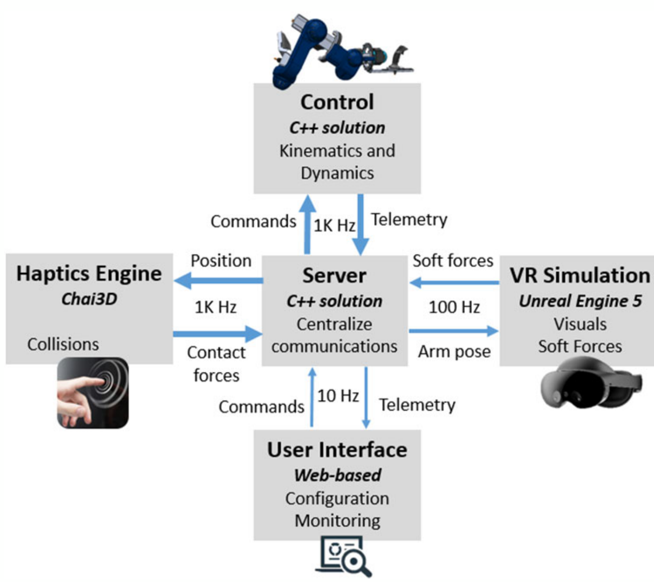
INTRODUCTION

Architecture



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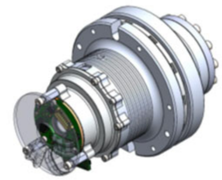
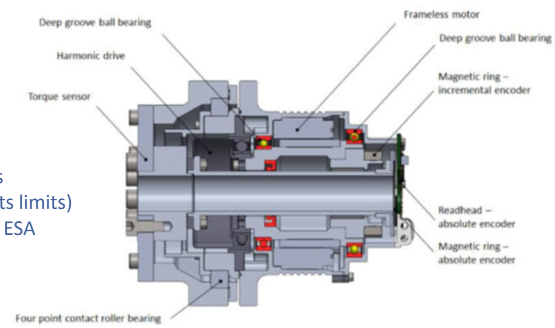
EXOSKELETON DESIGN

Previous iterations of exoskeletons at SpaceApps used capstan-based transmission, which increase the pulling capacity but require high maintenance

Custom BLDC motors

- Active joint sizes designed for 3 degrees of freedom
  - Heavy duty motor (87Nm): x2 units for shoulder abduction + flexion
  - Small duty motor (28Nm): x1 unit for the elbow
- Embedded sensors
  - Hall sensor
  - Incremental encoder
  - Absolute encoder
  - Torque sensor
  - Temperature sensor





- Direct transmission with hollow shaft offering high robustness
- Dimensioned to needs of astronaut training (forces, constraints limits)
- Design successfully tested in H2020 MOSAR, H2020 LUVMI or ESA MIRROR.

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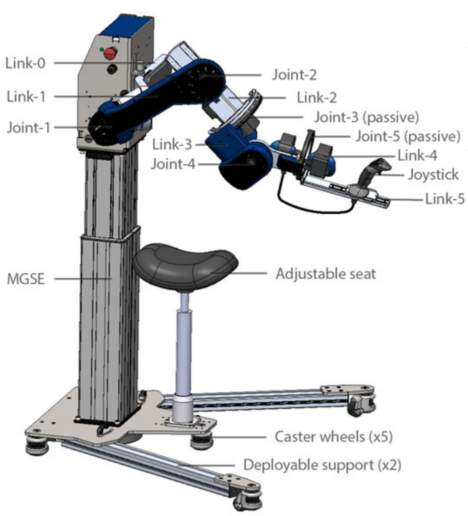
EXOSKELETON DESIGN

Structural Design



- Technology Demonstrator
  - 3 active degrees of freedom (custom BLDC motors)
  - 2 passive degrees of freedom (sensorized)
- Features
  - Robust: made of aluminum 7075-T6 and with anodized parts
  - Comfortable: ergonomic interface with paddings and Velcro straps
  - Compatible to P10-P90 percentile of adult European male/female range
  - Casing manufactured using Selective Laser Sintering 3D in Polyamide
  - Seated or standing configuration for users
  - Multiple safety protection layers in hardware and software
    - Mechanical end-stops limiting joint range
    - Safe Torque Off (STO) or Dead Man Switch
    - x2 emergency buttons
    - Software joint limitations
    - User Interface with "Stop" function
  - Portable with deployable support and caster wheels

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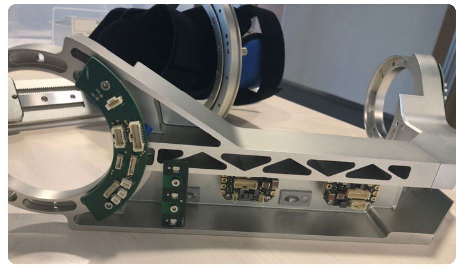
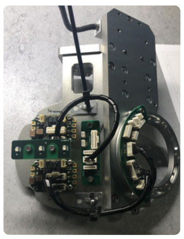
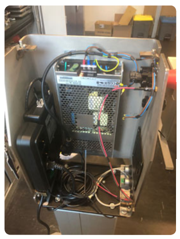
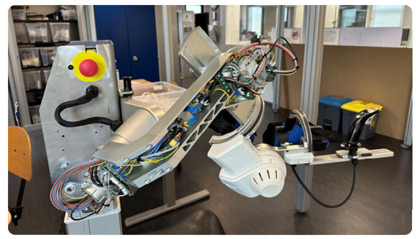
EXOSKELETON DESIGN

Integration





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SOFTWARE IMPLEMENTATION

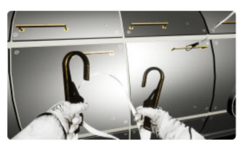
Virtual Reality Simulation

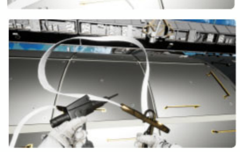
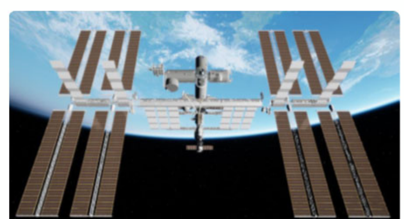
- Developed with Unreal Engine 5.1
  - VR compatible Nanite to virtualize complex geometries
- Standalone VR headset: Meta Quest Pro

- <u>EVA use case</u>

Perform displacements and operations with tools in microgravity

- Microgravity environment with
  - full model of ISS
  - Dynamic Earth model
  - Day-Night EVA training
- Extravehicular Mobility Unit (EMU)
  - Kinematic rig skeleton
  - Physics model
- Interactive tools
  - Handrails
  - Carabiners and Safety Tether
  - Pistol Grip Tool (PGT)
  - Others (CubeSat, screws…)

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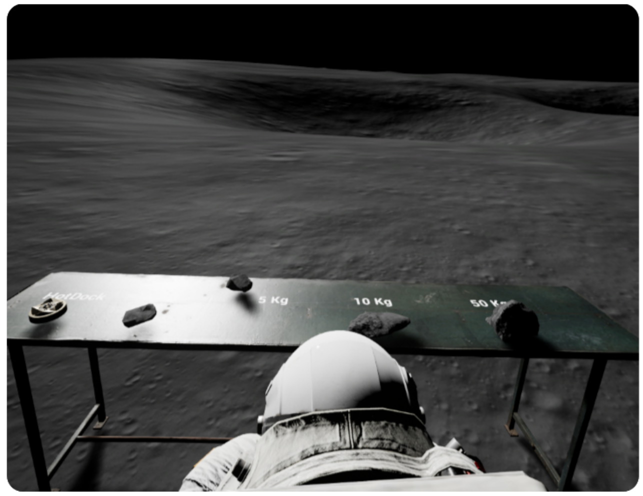
SOFTWARE IMPLEMENTATION

Virtual Reality Simulation

- Moon exploration demo
  - Landscape from real moon height maps
    - Data from Lunar Orbiter Laser Altimeter (LOLA)
    - South Pole of the Moon
    - Resolution of 5m/pixel
    - Landscape processed for VR
  - Test non-zero gravity compensation
  - Test grabbing objects of different weights
  - Locomotion in a vast landscape



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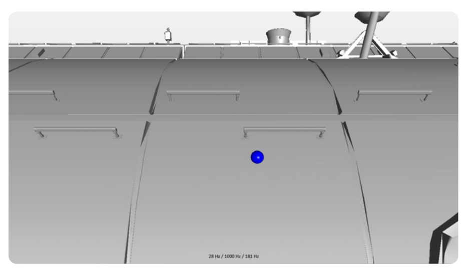
SOFTWARE IMPLEMENTATION

Haptics Engine

- Chai3D selected as main haptics software
- Fast-response forces. Frequencies of 1000Hz are necessary for stability.
  - Contact forces: result of touching surfaces within the virtual world

- Low-response forces can be generated by Unreal Engine 5.1
  - Inertial forces: Force generated by changing the velocity of a certain object, including yourself
  - Spring force: Force generated by the inflation of the suit that tries to put the arm in a stretched position



Haptic Engine Chai3D (top) and the VR simulation in Unreal Engine (bottom) are synchronized.
The blue ball represents the palm of the right hand and is used for the force feedback calculations.

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SOFTWARE IMPLEMENTATION

User Interface

- Web-based application.
- Developed using *NASA's OpenMCT* framework

- Functionalities
  - Configuration: Define the exoskeleton properties
  - Monitoring: Visualize the raw data from sensors
  - Commanding: Allow to test the exoskeleton
  - Terminal: Log of the actions with their status

- Other features
  - 3D view in real-time of the exoskeleton using URDF
  - Historic data: retrieve data from past sessions
  - Activate/Deactivate testing experiences
  - Adjust the kinematic and dynamic parameters
  - Test the LEDs and the motors

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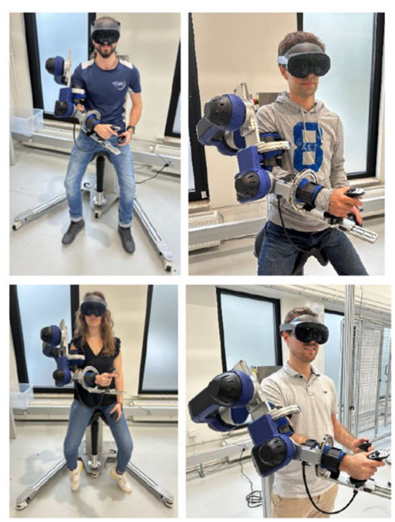
RESULTS AND DISCUSSION

- Currently, the system is undergoing **functional tests** prior its final integration
- **BLDC custom motors** are well suited to reduce maintenance and increase reliability, compactness, transparency and robustness compared to capstan, cable-driven transmission.
- The selected **ergonomic interface** with multi-point contact Velcro straps and fabric padding is a big improvement compared to previous iterations
- **Unreal Engine** is consolidated as best choice for VR simulation thanks to Nanite
- The use of **Chai3d** as haptics engine was decided to compute Contact forces
- The use of the **standalone VR headset** has proven to be more convenient
- The exoskeleton was designed to be a **Technology Demonstrator**
  - purposely featuring 3 DoF instead of 7 DoF
  - It shall help us validating that the selected technology is well suited to the next generation of training
  - Next iteration will be based on dual arms, hands + vestibular platform + VR headset for perception deception



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