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MARS-EXOS

Executive summary

As space exploration is becoming increasingly important, there is an urgent need for innovative systems to help the human body adapt to the hostile conditions that characterize other celestial bodies, such as the reduced gravity. Exoskeletons, together with Virtual Reality environments, could be used to simulate such environments on Earth so that astronauts can prepare for their missions. In recent years, the applications of exoskeletons have increased significantly. At the same time, technologies for virtual reality (VR) are also improving. The objective of the project is to integrate a lower limb exoskeleton in a 3D environment that reproduces the potential space stations located on Moon/Mars, where the exoskeleton simulates space operations typically carried out by astronauts, adapting itself to the different gravity. The overall work has been divided into three macro areas: the exoskeleton design, the creation of a VR environment of Moon/Mars base where to simulate the operations, and their final integration. The results are of great importance as they represent a new type of application that could be widely used in the near future, as the interest in space exploration grows. In the future, the intention is to expand the system so to support the simulation of a wider variety of movements, such as the operator bending down to pick up objects, the astronaut driving the rover out of the space station, etc. Moreover, the space base could be modelled in further detail and the proposed architecture could be turned into a real prototype to be worn by astronauts on Earth.

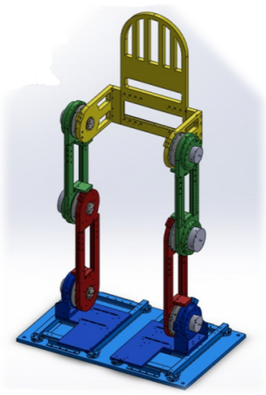
Key Words

Exoskeleton, Virtual Reality, Space exploration, astronaut training

Exterior View of the Moon Base in Unity

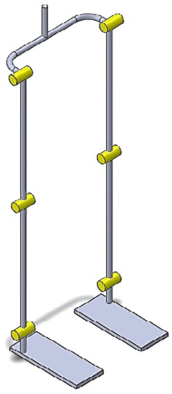
EXOS

From ESROB …



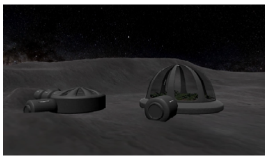
X Only sit-to-stand movement

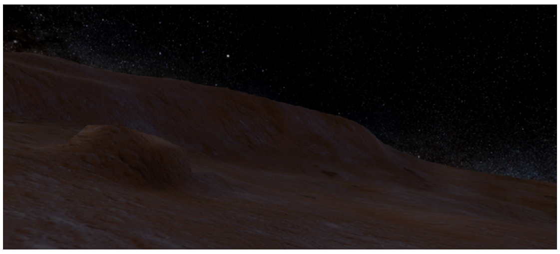
… to the exoskeleton simulator



V Simulation of the walk
V Sensation of reduced gravity

VR





V Environment building
V Modelling of interior and exterior assets
V Texturing of the models

INTEGRATION

THE COMMUNICATION SYSTEM

TCP/IPcommunication protocol

VR Environment on Unity

VR ⟶ EXOS

- Start / Stop command
- Desired walking curvature

Exoskeleton simulator

EXOS ⟶ VR

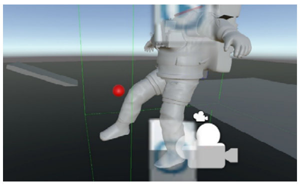
- Coordinates in the space of the foots, the hips and the centre of gravity
- Current walking direction

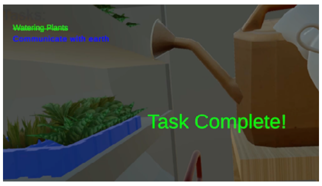
SIMULATION OF TASKS

Upper body
Oculus Quest 2 system

Lower Body
Exoskeleton's simulator

- Walking
- Watering plants inside the green house
- Call Earth from the control station
- Collect stone samples
- Drive the rover





Project description written by the Principal Academic Tutor

The project foresees:

- The use of an existing prototype of the exoskeleton (ESROB [1], supplied by the company SYCO) and its modification to make it suitable for space simulation.

ESROB is an exoskeleton with 3 degrees of freedom (DOF) with motors on the ankles, knees and hips to perform postural tasks on the sagittal plane, with joint legs and feet fixed on the ground. On the Cartesian postural space, the three possible coordinates are the angle of the trunk, the height of the pelvis from the ground, position of the centre of pressure (COP) on the feet's soles (balance). It is controlled automatically by biped robotics technology, or voluntarily by the wearer through admittance control from the EMG signals on the muscles of the legs and trunk. The two controls can be intermixed, leaving some DOF to the automatic postural loop and the complementary DOF to the user. The feeling of gravity from the user can be artificially modified by adding torques on the joints based on the Jacobian of the kinematic chain. It can be used to test balance in the sagittal plane in different gravity conditions and capability by the wearer to control it through biometric signals voluntarily.

- The integration of the exoskeleton with two virtual environments simulating, respectively, simulating a Mars Station located in the area of the Gale Crater on Mars and a Moon Station located in the area of the South Pole of the Moon.

- The testing of the designed system (Mars-Exos) on a VR treadmill (produced by the company Mars Planet Technologies: https://marsvrsys.com/motigravity/ to simulate the movement of astronauts in low gravity in Space while using the exoskeleton.

The activation of the following expertise demonstrates the multidisciplinary nature of the project:

- mechanical and sensor design
- medical knowledge for the study of the exoskeleton features.
- software development related to motion control.
- virtual prototyping and software development
- space technology

Team description by skill

- **Gilberto Manunza**, Data Science and Engineering at PoliTO. Preparation of assets to VR, modelling and texturing of 3D models, creation of the VR environment, development of the code for the Oculus and Exoskeleton integration.
- **Giorgio Scala**, Mechanical Engineering at PoliTO. Design of the sensors and control architecture. Design of the hardware architecture.
- **Greta Raina**, Aerospace Engineering at PoliTO. Design and sizing of the actuation system. Defining of how to manage the reduced gravity.
- **Karin Kay**, Architecture - Built Environment – Interiors at PoliMI. Preparation of assets to VR, modelling and texturing of 3D models.
- **Simona Civallero**, Mechanical Engineering at PoliTO. Gait analysis and design of the mechanical structure. Defining of how to manage the reduced gravity.

Goal

The aim of the project is to create a training tool for astronauts, which allows them to simulate the extra-terrestrial environments in which they will have to go during their missions. In particular, the purpose is to merge and integrate an exoskeleton with a virtual environment for the new space exploration application. In fact, before now, the integration of an exoskeleton with virtual reality has only been carried out in other fields of application, mainly in the medical one.
In order to achieve this goal, it is first necessary to define intermediate objectives, namely:

- From the exoskeleton point of view, the starting point is the ESROB exoskeleton provided by Syco company, that only allows for postural tasks [1]. Therefore, the aim is to define the modifications to theoretically apport to this exoskeleton so that it can also simulate the human walk, necessary for the most important activity that we want to integrate. Moreover, a way for the exos to simulate the reduced gravity values of Mars and the Moon must be determined.
- As regards the virtual reality, a complete virtual environment representing the Mars and Moon base must be created. Attention must be paid to all aspects of the virtual environment, both the interiors and the exteriors of the base, in order to create an environment that is detailed and as relevant as possible to reality.

The exoskeleton and the virtual reality, once the intermediate objectives just defined have been completed, are the starting point for the main goal of the integration. Specifically, it is necessary to allow real-time communication between the virtual environment and the exoskeleton simulator and the visualization of the astronaut's movements in the virtual domain. Finally, the objective is also to enable the implementation of new tasks and activities (not only walking), in order to make the experience more immersive and truthful.

Understanding the problem

As the interest for space exploration is growing, more and more astronauts will be reaching other celestial bodies in the following decades, starting from the two most sought-after destinations: Mars and the Moon.

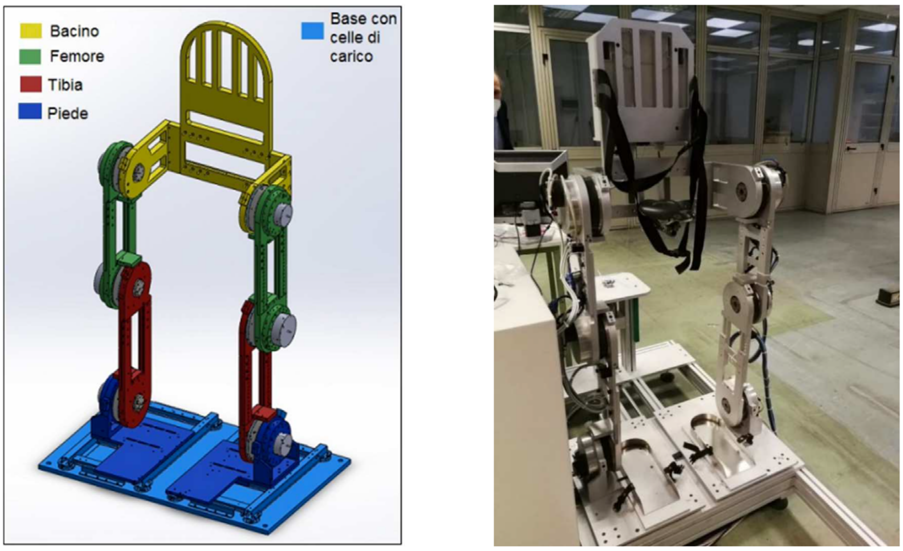
A mission of this kind presents several threats and requires huge efforts in terms of time, money and resources. This is why astronauts need to be prepared: every detail of the mission has to be simulated in advance, so to learn how to react to possible emergency situations and to be aware of how the human body will respond to living in hostile environments, such as those of Mars and the Moon.

However, specific tools for training astronauts to live in harsh environments are still hard to find. While virtual reality is already employed for this type of applications, its use is still limited. In order to provide the users with an immersive experience, able to really make them feel as if they were on the surface of another planet, VR itself is not sufficient, as it only involves the sight. This is why our solution integrates the VR with an exoskeleton, so to give the sensation of reduced gravity, which can be really strong in some cases: for instance, gravity on the Moon is about 16.5% of that on Earth. Thanks to this innovative system, for the first time astronauts will be able to see the space base that will host them for their future mission and walk inside and around it while feeling the effects of the reduced gravity environment on their body.

Exploring the opportunities

Virtual Reality (VR) concept dates back to the end of the 1960's and the beginning of the 70's. The first patented devices were introduced in the middle of the 1980's. In the early 1990's NASA developed a VR laboratory that was focused on extra vehicular activities in environments with microgravity. Nasa was indeed the first institution to actively include VR in its research. The US Space Shuttle Program marks the first successful practical use of virtual environment for its crew training in a mission for repair and maintenance of a space telescope. Since then, VR has been used for astronauts training, for assessing design solutions of space missions, for space craft assembly training and more [2][3]. Since then, there have been several other examples of the use of VR for space exploration. These tools often allow the training of astronauts in a cost-effective way. They also assist in exploring 'what if' scenarios of emergency situations and preparing better for a decision-making process. Nevertheless, the use of these tools is still limited.

In the last two decades, exoskeletons have become more and more common in the medical field. Their goal is to help the patient in recovering some movements that they no longer can perform. The exoskeleton aims to interact with the patient detecting his intentions and lightening the motion, but it's also integrated in a VR environment where the patient can perform a task or play a game. ESROB [1] is a perfect example of lower-limb exoskeleton for medical rehabilitation. In the recent years, the use of Electromyographic (EMG) sensors combined to a hierarchical control system has become essential to allow real-time data transmission, and the use of an anthropomorphic mechanical architecture that reproduces the human body and joint position has increasingly assumed a role of greater importance. Anyhow, most of the exoskeletons existing today are massive, heavy and difficult-to-wear. In the frame of space application, there are only a few examples of exos-VR interaction, most of them regard upper-limb exoskeletons controlling a robotic slave arm able to perform autonomously tasks in a zero-gravity environment. A training tool for astronauts that simulates the human walk by means of a lower-limb exoskeleton and adapts the movements to different gravities reproducing training tasks in an immersive virtual environment is still missing.



Exoskeleton ESROB, at Martoglio s.a.s

Generating a solution

The project presented as a solution integrates a lower limb exoskeleton in a 3D environment that reproduces the potential space stations located on Moon/Mars. The exoskeleton simulates space operations that are typically carried out by astronauts, adapting itself to the reduced gravity. The overall work has been divided into three macro areas: the exoskeleton design, the creation of a VR environment where to simulate the operations and their final integration.

Taking inspiration from ESROB able to perform postural exercises and the exos walking simulator provided by Syco Company, a new architecture was designed. The analysis of the gait cycle, and the calculation of the forces to be reduced in different gravity environments, has led to the creation of a new 3DOF mechanical model, able to simulate the human walk in the sagittal plane, involving the joint rotations of the hip, knee and ankles. Superficial EMG sensors, accelerometer/gyroscope placed on the back support, encoders on the joints and pressure sensors under the feet provide real-time data transmitted to higher control levels in a hierarchical way. The sizing of actuators was then essential to control the output forces simulating the reduced gravity and limiting the overall weight. The design depicts a valid concept for future implementations in real prototypes and reflects what the exos simulator used for the integration is able to simulate.

The virtual environment was created using Blender 2.8, which was used for modelling the terrain and the base assets, as well as their texturing. The assets were then arranged in an exterior and interior virtual environment of the Moon and Mars bases, using Unity 3D. A first-person player can move freely in these environments while simulating real physics such as the lunar/Martian gravity. The player can then perform tasks such as communicating with earth in the control room or watering plants in the greenhouse.

As regards the integration between the exoskeleton simulator and the virtual environment, this uses the TCP/IP communication protocol and was mainly implemented in the virtual environment of Unity. During communication, a series of strings and arrays are sent from one environment to another. In this way, it is up to the VR to decide when to start with the simulation and to define the walking curvature, and to the exos simulator to provide feedback on the current spatial coordinates of some points of interest and on the current direction.

During the simulation of the walk, the upper part of the astronaut in the virtual environment is moved based on the data arriving from the Oculus device. For the movement of the lower part of the body, on the other hand, we rely on the data coming from the exos simulator. The merging between the exos simulator and the VR is also completed for other activities, which can be done inside or outside the station. The tasks achieved inside the base are done without the exoskeleton, while those outside it can be conducted both with and without the exoskeleton. These additional activities are: watering the plants inside the greenhouse, communicating with Earth in the control room, collecting samples of stone outside the station and driving the rover (only the free play is allowed).

Finally, we added the Way Point system to the virtual environment intended for integration. It is a system that indicates to the player the tasks that can be performed using arrows and indicators, not making him/her feel lost in the virtual environment.

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[2] H. Aoki, C.M. Oman, A. Natapoff. Virtual-reality-based 3D navigation training for emergency egress from spacecraft. Aviat Space Environ Med 2007, 78: 8, 774–783, 2007.

[3] A. E. M. Casini, P. Maggiore, N. Viola, V. Basso, M. Ferrino, J. A. Hoffman, and A. Cowley. Analysis of a Moon outpost for mars enabling technologies through a virtual reality environment. Acta Astronautica, 143, 353–361, 2018.