Reduced Gravity Testing of Robots (and Humans) Using the Active Response Gravity Offload System

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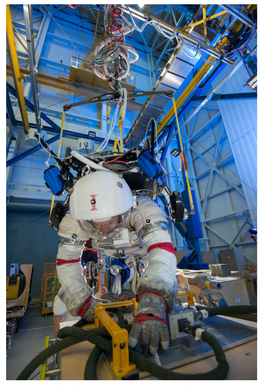
BACKGROUND

The Active Response Gravity Offload System (ARGOS) is a technology development project at the NASA Johnson Space Center (JSC) that provides high fidelity reduced gravity simulation for human and robotic testing. In development since 2007, ARGOS is a highly-dynamic human-rated robotic system, similar in appearance to an overhead gantry crane, that is capable of safely simulating any reduced gravity, including Lunar, Martian, and microgravity, over a test volume of over 340 m^3. While capable of high speeds up to 3.3 m/s, the system is designed for safe human testing with two-fault tolerance, rapid fault detection, and fast activation of the fail-safe emergency stop system, making it an ideal candidate for safety-critical reduced gravity testing. The system, currently in its third iteration, is operated at the Johnson Space Center for reduced gravity testing of humanoid robots, robotic rovers, space suit performance, astronaut training, and human performance studies.



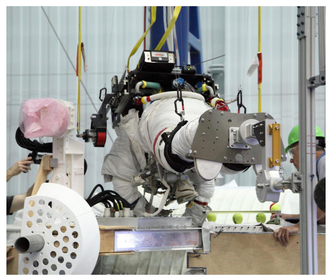
EMU Space Suit in ARGOS

Active Response Gravity Offload System (ARGOS) at JSC

ARGOS is capable of highly dynamic motions in all three axes using high power electric motors and fast sensing. At the same time, ARGOS is a high fidelity system that responds to very small inputs, enabling correct tracking of a variety of payloads in all reduced gravities. The system operates by measuring the load on the lifting cable and attempting to simulate the desired reduced gravity. As the payload induces a force up or down, the system simulates the motion in response, keeping the force error near zero and accelerating correctly. Simultaneously, the horizontal system senses the lifting cable angle, detecting small induced motions from the payload. The whole gantry then moves in the horizontal plane above the payload to maintain a vertical lifting force while also simulating Newtonian motion.

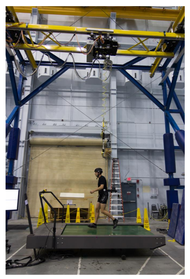
SAFETY SYSTEMS

ARGOS was designed from the start for human testing, where the human needs to be kept safe by a fast-acting safety system. As such, it is designed to be fully two fault tolerant with robust safety systems that can activate and safe the robot by applying brakes in the event of a fault. The overall safety system philosophy of ARGOS is to stop and safe the robot as quickly as possible in the event of the detection of a fault, as procedures and a test team exist to re-start the test or remove the payload or test subject. In addition, a device is used on the lifting cable to limit shock loads induced into the payload in the event of a high-speed stop. ARGOS achieves its two fault tolerance using a variety of methods, including redundant sensors, a real-time safety model to predict the state of the system and monitor for undetected faults, and an independent overspeed detection system. In addition, extensive reviews and analysis of the system and its architecture were performed prior to deploying the system at NASA.



Alpha Magnetic Spectrometer (AMS) Repair Training with Crewmember in Foot Restraint

Robonaut2 in ARGOS

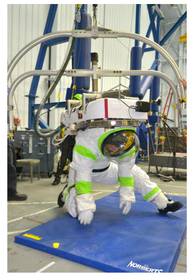


Treadmill Running

TESTING AT NASA

Human Testing: Human testing in ARGOS supports a variety of objectives and programs, primarily in microgravity, Lunar gravity, and Martian gravity. These include: Human performance testing and analysis, evaluation of new tools, space suit evaluation and analysis, astronaut training and evaluation, EVA procedure development, exploration and geologic evaluations, and human factors research.

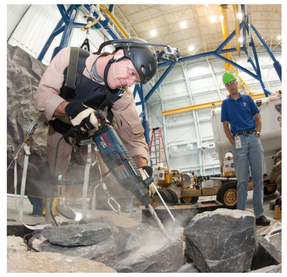
Space Suit Evaluations



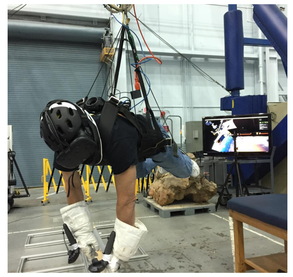
Planetary Fall Recovery

Planetary Shoveling

Asteroid Translation



Asteroid Sample Collection

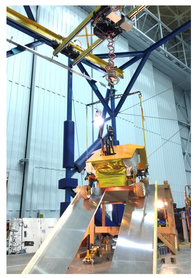


Training using Hybrid Reality

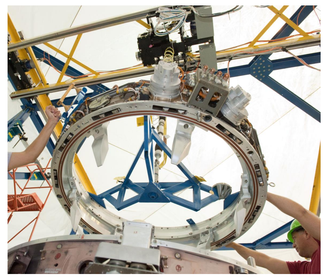
Fire Extinguisher Evaluation

Robotic Testing: Robotic testing in ARGOS has supported reduced gravity testing of non-human payloads in a variety of gravities. The primary robotic payloads in ARGOS have been the Robonaut2 (R2) humanoid robot, which uses ARGOS to practice microgravity walking and tasks, and the Resource Prospector (RP) Rover, which uses ARGOS to evaluate performance in a realistic Lunar gravity environment. Additional testing has included a sample return microcapsule, the Simplified Aid for EVA Rescue (SAFER) unit, docking adapter assembly procedures, and vacuum cleaners.

Robonaut2 Training



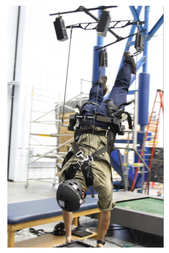
RP Rover Lunar Testing



Docking Adapter Installation Testing

GIMBAL MECHANISMS

A variety of payload interface gimbals, which are passive mechanisms offering one to three degrees of rotational freedom, have been developed at NASA to interface to human and robotic payloads. The gimbals are adjustable to align the payload center of gravity (CG) with the gimbal, and the human gimbals are fully adjustable for the 1-99% subject. All are designed to minimize mass and induced moments of inertia to minimize their effect on the payload. Proper harnessing of the payload is crucial to a realistic test. Incorrect CG alignment, a high inertia gimbal, or too few rotational degrees of freedom can all contribute to false data during the test, minimizing the benefits provided by the capabilities of ARGOS. As such, one of the keys to successfully testing in ARGOS is to select or design the correct gimbal for the desired testing.

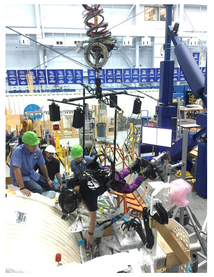


Microgravity Gimbal

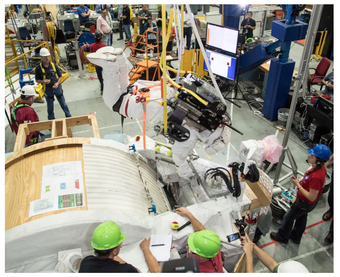
KEY CAPABILITIES

1. Simulates **partial gravity and microgravity** and can shift between gravities seamlessly
2. **Realistic reduced gravity motion** in all three axes, including constant velocity coasting
3. System is **two fault tolerant** and detects faults in **less than 20 milliseconds**
4. Simultaneously able to support **high dynamics** and **high fidelity**
5. No **water drag** or limitations imposed by an **underwater environment**
6. The test team is **co-located** with the test subject or payload during the entire test
7. **Virtual walls, floor, and ceiling** in software to protect the payload and prevent falls
8. **Virtual Reality** (VR) can be integrated for a **comprehensive simulation experience**
9. **Test article integration** to pass telemetry or other data from the payload to ARGOS
10. **Rapidly reconfigurable floor** allows for quick changes between unique test setups

Human Performance Study in VR



AMS Tool Evaluations



AMS Repair Mission Evaluations

ARGOS SPECIFICATIONS

Vertical Offloading System:

Payload Capacity: 340 kg (750 lb)
Sensitivity: < 0.0005 kg
Maximum Speed (140 kg Payload): 3.3 m/s
Maximum Speed (340 kg Payload): 1.4 m/s
Max Acceleration (140kg Payload): 24.4 m/s^2
Max Acceleration (340kg Payload): 10.2 m/s^2
Working Height: 5.5 m

Horizontal Tracking System:

Maximum Speed: 2.0 m/s
Max Acceleration: 6.1 m/s^2
Sensitivity: < 0.1° of cable angle
Y Travel: 11.0 m
X Travel: 5.8 m

CURRENT AND FUTURE PLANS

As a technology development project, ARGOS is under continuous development at the NASA Johnson Space Center. Currently, work is being done to continuously improve the performance of the system to ensure it meets current and future customer needs. In addition, virtual reality is actively being integrated into ARGOS to enable training and human performance studies in a hybrid or virtual reality environment. The first human performance study using virtual reality in ARGOS was recently completed in a Martian gravity simulation.

The ARGOS project is also seeking to extend this technology into the medical rehabilitation field, where its high fidelity reduced gravity offloading in all three degrees of freedom, along with its safety systems, could be highly beneficial for patients rehabilitating from lower limb injuries, spinal cord injuries, or strokes.

CONTACT

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