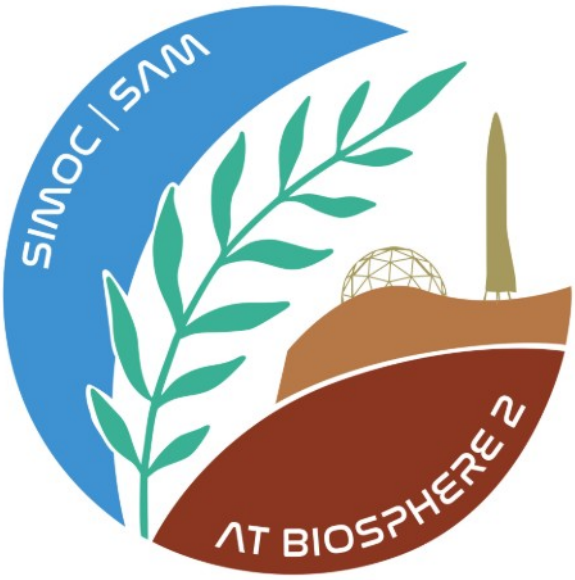

Research papers from MDRS, HI-SEAS, and LunAres since their respective inceptions

researched and edited by Natasha Nichols, PhD

for the Space Analog for the Moon & Mars (SAM)

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Natasha Nicholson	Kai Staats, Director at SAM	February 2024

Analogue Descriptions

Private Ground Infrastructures for Space Exploration Missions Simulations

Souchier, A., **2010**. *Acta Astronautica*, *66*(11-12), pp.1580-1592.

Keywords: ***MDRS***, *FMARS*, *overview*, *training*, *planning*, *geography*, *analogue and simulations*.

Abstract

The Mars Society, a private non profit organisation devoted to promote the red planet exploration, decided to implement simulated Mars habitat in two locations on Earth: in northern Canada on the rim of a meteoritic crater (2000), in a US Utah desert, location of a past Jurassic sea (2001). These habitats have been built with large similarities to actual planned habitats for first Mars exploration missions. Participation is open to everybody either proposing experimentations or wishing only to participate as a crew member. Participants are from different organizations: Mars Society, Universities, experimenters working with NASA or ESA. The general philosophy of the work conducted is not to do an innovative scientific work on the field but to learn how the scientific work is affected or modified by the simulation conditions. Outside activities are conducted with simulated spacesuits limiting the experimenter abilities. Technology or procedures experimentations are also conducted as well as experimentations on the crew psychology and behaviour.

Operational Results of the EuroMoonMars-B Analogue Campaign at the Mars Desert Research Station

Cross, M.D., Battler, M., van't Woud, H., Ono, A., Orgel, C., McIsaac, K., Foing, B. and Maiwald, V., **2014**. In *AIAA SPACE 2014 Conference and Exposition* (p. 4469).

Keywords: ***MDRS***, *Analogue mission summary*, *general*, *operations*, *human factors*, *science*, *research*, *exploration*, *robotics and automation*, *human-factors*, *EVAs*, *delayed comms*, *stress*, *EuroMoonMars*

Abstract

We present the summary of results of the 2013 EuroMoonMars-B analogue operations mission conducted at the Mars Desert Research Station (MDRS). The two-week campaign involved a series of operations, human factors, and scientific exploration research towards goals of the International Lunar Exploration Working Group (ILEWG). The primary research objectives revolved around the operations to conduct field geology to identify targets of astrobiological interest, and to provide recommendations for future crewed expeditions for increasing the science return based on improved resource allocation. These activities include assessment of robotic and automation tools for assisting geologists to increase the efficiency of time spent on extra-vehicular activities (EVAs); crowd-sourced mapping to identify potential target regions to send the geologists on EVA based on orbital imagery; efficiency of crew time allocations; and habitat-based human factors to reduce stress levels during operations. Secondary objectives towards those goals included a low-bandwidth Earth-Moon time-delayed communications experiment.

Mars Desert Research Station: Crew 138

Roman-Gonzalez, A., Saab, B., Berger, J., Hoyt, J., Urquhart, J. and Guined, J., **2015**. In *66th International Astronautical Congress-IAC 2015* (p. 7).

Keywords: ***MDRS***, *Analogue mission summary*, *general*, *operations*, *logistical evaluations*, *research*, *geological field mapping*, *engineering and electrical COTS components*, *crew activities*

Abstract

Crew 138 was comprised of a team of highly-skilled professionals with varied backgrounds who were selected by the Mars Society to undertake a two-week interdisciplinary expedition at the Mars Desert Research Station near Hanksville, Utah. The Crew's activities ranged in scope from preparing operational handbooks and checklists for the Mars Desert Research Station, performing hardware and logistical evaluations for future research at MDRS, an analysis of Google Earth as a tool for geological field mapping, evaluations of commercial-off-the-shelf engineering and electrical components, the design of a Mars EVA work day functional task battery, and assessing the viability for incorporating an exercise countermeasures hardware and program into the Mars Desert Research Station.

Glance into the future: research steps on a path to a continuous human presence on Moon, Mars and beyond

Maiwald, V., Quantius, D., Schubert, D., Zabel, P., Zeidler, C. and Vrakking, V., **2016**. *Acta Futura, vol*, *10*, pp.45-59.

Keywords: ***HI-SEAS***, *MDRS*, *Analogue mission summary*, *summaries*, *general*, *greenhouse technology*, *power*, *illumination*, *EuroMoonMars*

Abstract

Humans have been present in space for five decades and the dream of travelling and exploring space is even older. The next major step after a prolonged human presence on low Earth orbit is a prolonged human presence on other solar system bodies like Moon, Mars or even beyond. Since mid-2011 one research field of the System Analysis Space Segment (SARA) department of DLR has been the establishment of human outposts in the form of space habitats. This paper aims to showcase these activities and summarize their most important results in three primary branches. First, the design of a facility for the integrated testing and qualification of habitat technology on Earth. Second, one of the department's core competencies: Space greenhouse technology. This paper explains which steps, from concept over breadboard to laboratory work, eventually led to the current design, construction and operation of a space greenhouse analogue in Antarctica as well as the relevance for future space missions. The third branch, mainly intended to bolster the theoretical work with more practical insight into habitat design and operation are the analogue test site missions conducted by the department in 2013 and 2014. It is explained how these missions helped with the design and development of the current hardware projects and the future research facility.

Anthropology

Resonant worlds: Cultivating Proximal Encounters in Planetary Science

Messeri, L., **2017**. *American Ethnologist*, 44(1), pp.131-142.

Keywords: ***MDRS***, *Anthropology*, *analogy*, *planetary science*, *resonance*, *anthropology of science*

Abstract

Planetary scientists are adept at producing knowledge about objects that are far removed from their lived experience of place and time. Sometimes, they overcome this distance by positioning Earth as a planet that can stand for other worlds. Encountering Earth becomes an encounter with another planet. When scientists experience the Earthly as otherworldly, they sometimes feel an excitement here described as "resonance." Fully felt resonance is rare, but scientists devote much time and effort to preparing for it so as not to miss its fleeting instances. Just as resonance affords scientists the possibility of experiencing the distant, it also describes moments when the anthropologist is in harmony with what had previously been strange. Thus, resonance is a mode of cognitive and affective reasoning that collapses distance and transforms the similar into the same.

Wor(l)d□Building: Simulation and Metaphor at the Mars Desert Research Station

Black, A.D., **2018**. *Journal of Linguistic Anthropology*, *28*(2), pp.137-155.

Keywords: ***MDRS***, *Anthropology*, *linguistic anthropology*, *linguistics*, *metaphor*, *imagination*, *human spaceflight*, *cognitive anthropology*

Abstract

Using the framework of Critical Metaphor Analysis (Charteris-Black 2004), this paper analyzes metaphorical production at an analog research campus—the Mars Desert Research Station. This analogy to the potential reality of human existence on Mars offers an opportunity to study language use as speakers "make sense" of their experiences in a simulated physical and social unknown. This process is key to understanding how metaphor functions to "wor(l)d-build" by facilitating the cognitive processes that bridge human imagination and emergent reality. This research demonstrates that metaphor is not always about physical experience, but can be shaped by imagination. Subtle shifts in conceptions and expression, such as those prevalent in this study, are symptomatic of larger processes of knowing and potentially inhibiting knowledge about experience.

Architecture & Engineering

Extreme Living Solutions: Self-Sufficient Habitat for Extreme Environments Based on Space Technology

Schlacht, I.L., Ono, A., Karga, V., Mangeot, A., Roetting, M., Masali, M. and Foing, B., **2012**. In *Proceedings from 63rd International Astronautical Congress (IAC)*.

Keywords: ***MDRS***, *Architecture LSS*, *self-sufficient system*, *autonomous habitats*, *sustainability*, *technology transfer*, *space architecture*, *Melissa*.

Abstract

This paper presents the first research phase of a system based on space technology that is capable of increasing habitability in extreme environments on earth. In this scenario, this research aims to support the establishment of a self-sufficient and minimum habitat from consulting to construction based on minimum space, time and costs. Extreme environments are places for which human beings are not fully suitable, such as an environment where the water is contaminated because of a natural disaster. To support habitability in such conditions, this paper approaches research on autonomous habitats based on space technology, such as the water recycling system used today on the International Space Station. But what happens in such isolated habitats from a psychological side? In an extreme situation, the habitability project needs to be approached from a multidisciplinary dimension, considering all the different aspects as part of holistic (Holos: all) research. Indeed, space research can be applied both to technology transfer and to research transfer, including, for example, psychological research. This project would start by providing consultancy services for users who want to improve extreme habitability projects and later on evolve towards building minimum habitats for extreme environments, to be used in isolated conditions, disaster situations or even in urban settings. The investigation (capturing space dimensions, volumes, people, traffic, and interaction flow) will serve users in terms of the quantitative assessment of habitability and ergonomics for habitats in extreme or stressed environments. The research will be validated using data from the Mars Desert Research Station and other cases.

MDRS – Mars Analog Outpost Growth

Doule, O., **2014**. In *AIAA SPACE 2014 Conference and Exposition* (p. 4407).

Keywords: ***MDRS***, *Architecture*, *EVA*, *ground-truthing*, *geomorphology*, *meteorology*, *sustainability*

Abstract

This paper introduces a vision for the realistic expansion of the MDRS analogue base following personal habitation experience during the crew 135 mission RAR. The vision is based on a space architecture perspective of a real space mission, DRM 3, and current analog base requirements with emphasis on safety and sustainability of crew operations. The outcomes are presented in the form of a concrete case study and an infrastructure expansion concept for the MDRS that could host either more research facilities, crew or a larger greenhouse and emergency and safety structures. This project required a crew of two for exploratory EVA, surveying of the surrounding neighbourhood, ground-truthing of local geomorphology, and monitoring of local weather patterns.

Advice from Ares: Enhancing Habitat and Life Support System Design with Martian and Lunar Analogue Test Site Missions

Maiwald, V., Poulet, L. and Schubert, D., **2014**. In *63rd International Astronautical Congress (IAC)*.

Keywords: ***MDRS***, *Architecture*, *LSS*, *structural engineering*, *greenhouses*, *energy*, *power*, *illumination*, *efficiency*, *reliability*, *redundancy*, *nutrient delivery*, *GreenHab*, *EuroMoonMars*

Abstract

Since mid-2011 the German Aerospace Center Institute of Space Systems has been working in the field of habitat design, specializing also in life-support systems within the project EDEN. Having conducted several design studies about off- and on-planet habitats and greenhouse systems, the Department of System Analysis Space Segment had the opportunity to participate in the International Lunar Exploration Working Group's EuroMoonMars B mission (Crew 125) at the Mars Society's Mars Desert Research Station (MDRS) in early 2013. This participation took place mainly under the auspice of relating the analogue test site with the habitat design studies of the department and to prepare future missions with the perspective of greenhouse system tests. One year later in 2014 the department participated in the Reliability and Redundancy of Extreme Environment Habitat Structures and Power Systems mission (RAR Mission) within Crew 135. The main focus of the mission has been structural and power assessments to improve habitat performance, efficiency, reliability and redundancy. In particular a study on illumination and nutrient delivery systems of the GreenHab was performed to make it more efficient in terms of plant production and crew time use. The authors present in this paper an overview about the research conducted off-site, describe the status of MDRS and the missions and elaborate the experiments and lessons learnt during the Crew 125 and Crew 135 participation. It is shown how analogue test site utilization enhances the department's research in the field of habitat and life support system design and in general the preparation of human missions to Moon and Mars.

Failure Modes and Criticality Analysis of the Preliminary Design Phase of the Mars Desert Research Station Considering Human Factors

Oguz, E., Kubicek, M. and Clelland, D., **2018**.. *Reliability Engineering & System Safety*, *178*, pp.247-254.

Keywords: ***MDRS***, *Engineering*, *FMECA analysis*, *maintenance strategies*, *design engineering*, *system modification*, *reliability*, *human factors*, *human design approach (HDA)*, *optimization*, *access and inspection*, *environmental impacts*

Abstract

This work presents an extension to the traditional FMECA (Failure Modes, Effects and Criticality Analysis) method to include the effects of human factors concerning accessibility/repairability, probability of contact and degree of contact. The authors refer to this extension to the traditional FMECA as the Human Design Approach (HDA). All data used in this study was collected during the stay of two of the authors at the Mars Desert Research Station (MDRS) in the Utah desert, USA. The MDRS is a laboratory for carrying out research in order to understand and investigate the difficulties of how to live and work on another planet. The results show that following the HDA can enhance the safety and reliability of the MDRS. There is still a significant amount of research required concerning reliability analysis of the space habitat in terms of the selection of optimum designs, the modification of systems, as well as access, inspection and maintenance strategies, human factors and environmental impacts. This preliminary study will assist the design engineers with the selection of an

optimum configuration for space habitats and can be extended to any case where humans can influence function of an environment.

Lunar Daytime: Architectural and Behavioral Experiments in a Space Analog Habitat

Cohen, M.M., De Leon, P., Bishop, S., Barker, D., Bianco, S., Häuplik-Meusburger, S. and Gentile, R., **2019**. In *49th ICES 2019-Boston* (p. 16).

Keywords: ***HI-SEAS, MDRS****, Architecture; Human Factors; Psychology; Architectural Research; Analog Habitat; Behavioral Science; Environmental Psychology; Experimental Data; Human System Integration; Space Architecture*

Abstract

The Lunar Daytime concept addresses the challenge to behavioral scientists and architectural researchers in conducting research in space habitats or habitat analogs to produce scientifically valid results. Historically, researchers were limited to largely qualitative surveys. Instead, the Lunar Daytime (LDT) team will demonstrate the efficacy of a modifiable environmental habitat analog laboratory capable of producing empirical, measurable, and quantitative data sets. To measure effects on crew performance and crew behavioral responses as a dependent variable, researchers must be able to make and control changes in the physical living and working environment as an independent variable. Lunar Daytime refers to modeling an early human-tended lunar base. Because this surface mission depends on solar energy for power, which is available only during the lunar day, the time limit to the simulation is 14 days, but may run shorter. This LDT context provides the mission scenario to conduct these comparatively short-duration habitat analog studies. A benefit of two-week long simulations is that it becomes possible to conduct multiple test runs within the same time and budget that a much longer (i.e. Mars mission) scenario would require. The LDT team has conducted extensive studies of space vehicle and habitat design, done research in various analog habitats (e.g., MDRS, HERA, HI-SEAS, Concordia), and reviewed all existing space habitat analog facilities. Unfortunately, none of the current facilities allow for the degree of modification necessary to experimentally address the critical issues surrounding creation of the optimally built habitat. Major Objectives: 1) Create a space habitat analog research facility, specifically designed to accommodate desired modifications in the physical and perceptual living and working environment, and 2) Demonstrate the ability of such an environmental behavioral laboratory to simulate, investigate, and address critical factors that play important roles in human health and well-being in Isolated and confined environments (ICEs).

LunAres Analog Research Station—Overview of Updated Design and Research Potential

Mintus, A., Orzechowski, L. and Ćwilichowska, N., **2022**., *Acta Astronautica*, *193*, pp.785-794.

Keywords: ***LunAres,*** *Architecture, habitat design, human missions, sustainability, technical solutions*

Abstract

LunAres Research Station is an analog research station for crewed space mission simulation, located at the abandoned airport in Poland. The facility provides full isolation, allowing for complex research on the psychological and physiological impact of long-term extra-terrestrial human presence. The general objective of LunAres is to create a research platform to support scientific and technological development in human space exploration. A broad range of specialists is involved in the study from fields like extreme medicine, psychology, biotechnology, robotics and engineering, sociology,

architecture. The possible observation and control of the indoor environment, as well as telemetry of the crew's physical and psychological states, provide large quantities of data for complex studies.
This paper presents an overview of the LunAres Research Station activity since its establishment in 2017. The contribution to scientific research and technology development is included. Based on the presented experience of carried missions and crews' feedback a roadmap regarding the station design advancement is determined. The decision-making process of development is presented finalized with the demonstration of the potential for future projects and studies regarding human missions and sustainability. The conclusions of upgraded functional plans and spaces were determined through research on existing references and the new strategy for LunAres. Detailed drawings regarding architectural and technical solutions as well as future steps will be introduced.

About Architecture in Extreme Conditions. How Can Space and Extreme Environment Help Architects Design Better?

Dziaduła, W. and Fross, K., **2022**, *73rd International Astronautical Congress (IAC)* (pp. 18-22).

Keywords: **LunAres**, Architecture, self-sufficiency, extreme environments, space design, climate change

Abstract

In 1988, Dr Wolfgang Feist, together with the Institute of Housing and Environment, developed the first assumptions for a passive building. And although energy-saving architecture has been known to architects for so long, it is only now starting to become popular. This is caused not only by trends and situational awareness in design but also by newer directives and requirements for newly designed facilities. The next step is the development of a new generation of self-sufficient architecture, i.e. one that responds to the increasing environmental challenges related to extreme climate change. What now seems to be the norm and convenience may become unavailable to us in the future, and it will be necessary to adapt to new, more difficult conditions. The extreme conditions in which we live and work are known today, and functioning there is mastered (to some extent) to perfection. Such environments are, for example, polar areas, deserts, and underwater environments. People have adapted (also thanks to architecture) to function at polar stations or submarines and even in such an extreme environment as space. The article presents an overview of selected projects in extreme conditions (including polar stations, submarines, and underwater research stations), including projects in space and analog habits, and a detailed description of the applied solutions from the architecture to find solutions and design ideas that can be implemented in the self-supporting construction of the future. The work provides answers to the questions: how can architecture in extreme conditions have an impact on future construction and architecture? How can solutions be implemented in space architecture to help in building the idea of a sustainable, self-sufficient environment? Why should every architect design at least one habitat in space? The work also includes an analysis of the feasibility of transferring individual solutions and ideas for adapting individual solutions in designing now and in the future.

Art

The Agency of Human-Robotic Lunatics

Pell, S.J., **2018**, October. The Agency of Human-Robotic Lunatics. In *Proc. 69th International Astronautical Congress, Bremen DE* (pp. 1-5).

Keywords: ***LunAres***, *Art, augmented reality (AR), virtual reality (VR), VR mapping, space culture, human factors, astronaut performance, technical performance, interaction design, human-robotic interactions, LiDAR imaging, spatial awareness, orientation, geographic familiarization, remote and in-situ operational training, EVA performance capabilities*

Abstract

Imagination is our window into the future. Led by each generation of artists and scientists, it is through their explorations and inventions that we push towards the edges of possibility. Aerospace developments are no exception and like other areas of human endeavor we are witnessing the increased use of robots as the technological tools for humans to make our visions of the future a reality. Remembering that you can architect the future, what lunatic ideas can we conceive, believe and achieve? Presenting The Agency of Human-Robotic Lunatics (2017) a live keynote performance set underwater and on the Moon that premiered at Robotronica 2017. We saw the artist-astronaut's live performance blend with VR mapping of historical lunar orbital reconnaissance imaging data, and augmented reality artifacts from a real spacewalk simulation underwater during Project Moonwalk. Project Moonwalk develops and tests technologies and training procedures for future missions to the Moon. Through the use of an autonomous subject tracking robotic camera system, the Cinema Swarm, the artist-astronaut articulated the range of human-robotic and human-aquatic interactions unique to Project Moonwalk. The parallel design of human-robotic performance protocols undersea and human-cinematic robot performance onstage inspired new modes of transdisciplinary dialogue to understand affective visualization applications in astronautics. The technical concepts led to the Spatial Performance Environment Command Transmission Realities for Astronauts SPECTRA (2018) experiments that further expanded the protocols of confined/isolated Lunar Station analogue mission simulations [LunAres 3 Crew] with transmission of LiDAR imaging and the choreographers' moves for an artist-astronaut's interpretation on the analogue Crater. The SPECTRA experiments demonstrated a direct impact on the astronaut's range of spatial awareness, orientation, geographic familiarization, and remote and in-situ operational training for amplifying performance capabilities on EVA. The significance of these new approaches is the widening of the definition of both technical and cultural activities in astronautics. Outcomes also signal new research and impact pathways for the artist, astronaut and avatar in space exploration and discovery.

The Artist, Astronaut, and Avatar in Space Exploration

Pell, S.J., **2018**. In *Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play* (pp. 3-3).

Keywords: ***LunAres***, *art, LiDAR, spatial awareness, orientation, geographic familiarization, remote and in-situ operational training, EVA performance capabilities, human-robotic interaction, training, mixed reality*

Abstract

Human expression and connection fuels our evolutionary humanity, curiosity and passion. So how far can we go? Pell is designing modes for following the body's natural edge to the abyss of space. New works including the parallel design of human-robotic performance protocols undersea and human-

cinematic robot performance onstage, have inspired new modes of trans-disciplinary dialogue to understand affective visualization applications in performing astronautics. Technical concepts derived through play and performance on EVA (extra vehicular activities or spacewalks), have led to the development of technical configurations supporting the Spatial Performance Environment Command Transmission Realities for Astronauts SPECTRA (2018). Various SPECTRA experiments on Moon/Mars analogue missions have expanded protocols, for example the confined/isolated Lunar Station analogue mission simulations [LunAres 3 Crew] with transmission of LiDAR imaging and the choreographers' moves for an artist-astronaut's interpretation on the analogue Crater. Pell has demonstrated that interactions with SPECTRA systems have a direct impact on the artist-astronaut's range of spatial awareness, orientation, geographic familiarization, and remote and in-situ operational training for amplifying performance capabilities on EVA. The significance of these new approaches is the widening of the definition of both technical and cultural activities in astronautics through play and performance. Other research from cinematic robotics, and mixed realities including virtual reality, LiDAR projects and big data immersive visualisations platforms, to an astronaut dance is about designing systems for improved performance and cultural engagement for exploring the critical pathways, discourse and cultural practice surrounding space as inspiration for new works of art, and new ways of working with art and space, during a unique mission simulation. These opportunities also support safe forums for reflexive analysis of our human ambitions, and indeed our assumptions, about a human return to the Moon, and future extra-terrestrial culture. SPECTRA tools translate visions for architecting a new era of spaceflight. Outcomes also signal new research and impact pathways for the artist, astronaut and avatar in space exploration and discovery.

Apollo and the Muses: A Preliminary Discussion of the Cultural and Technical Inspirational Knowledge Embedded in the Lunar Space Arts of an Analogue Mission

Pell, S. and Barnes, D.G., **2019**, October.. *70th International Astronautical Congress* (IAC) (pp. 21-25).

Keywords: ***LunAres***, *Art*, *culture*, *broadcast*, *communications*, *spatial awareness*, *visualisation*, *data transmissions*, *immersive media*, *mixed reality*, *human-robotic interaction design*, *translocation communication*, *interdisciplinary human performance research*

Abstract

Nine contemporary art and cultural research projects were integrated within a 15-day isolated and confined lunar analogue mission simulation. The mission architecture, uniquely customised and curated for the specific parameters of the LunAres Moon/Mars Station in Poland, 2018, also played to the strengths and interests of the transdisciplinary SPECTRA crew. As mission commander, responsible for crew selection, cohesion and project curation, my practice focused on human expression and performance, and the challenges of broadcast and communication. For the duration of the SPECTRA mission, I collaborate with the Monash Immersive Visualisation Platform [MIVP] and various remote partners including Lucy Electric LLC and Space Garden Company. MIVP teams produced tools for spatial awareness during simulated EVAs in terrestrial analogue sites, and post-processing large data transmission between global sites for affective visualisation in the CAVE2 and the Monash Future Control Room. Together we designed tactical laboratories for experimental arts to support performance within extreme operational isolated confined environments. Artefacts included immersive media, mixed reality, human-robotic interaction design, and new systems for live art and translocation communication and interdisciplinary human performance research published in Live, and VR formats. Outcomes were real and speculative, poetic and practical with high technical cultural value and human factors benefits during and post-mission. The success of the SPECTRA mission demonstrated ways that the cultural and technical cooperation embedded in the lunar space arts program could give value to the arts and science goals of missions today. Our inspiration was the Apollo programme. While primarily about space exploration, it also represented a meeting of political,

technological and ontological paradigms through a global media spectacle, to become a significant moment in cultural exploration. Apollo broadcast and communication achievements for example, conjured inspirational and practical knowledge useful for future lunar mission architectures and the lunar analogue SPECTRA mission.

Human Spaceflight Performance: Bootstrapping the Intersection of Biometrics and Artistic Expression Through Planetary Mission Analogue EVAs.

Pell, S.J., Kobrick, R.L. and Barnes, D.G., **2019**. In *International Astronautical Congress (IAC) 2019* (pp. 670-684),International Astronautical Federation (IAF).

Keywords: ***LunAres***, *Art, Biometrics, biomedical devices, simulated EVAs, crew training, survival training, mission scenarios, problem solving*

Abstract

Human spaceflight activities often compartmentalize projects by domain, but it is hypothesized that data sets gathered within interdisciplinary frameworks can produce the richest outcomes. This research investigates the intersection of projects native to both hemispheres of the brain to offer a new methodology for proposing research projects focused on using planetary mission analogue extravehicular activities (EVA). These simulated, multi-permutation, EVAs are critical for preparing humans for missions to the Moon or Mars. Minimal investment is required to train a crew in an extreme environment compared to actual spaceflight and locations can enlighten and influence our exploration plans ranging from how we design life support equipment, tools, and assess workload to human behaviour, joy, and play, i.e. our culture. Collaboration by the authors has occurred at the Mars Desert Research Station (USA), LunAres MoonMars Research Station (Poland), and with the Mars Academy USA NEAMAE Project (Nepal). Biometric tracking of astronauts is a well-understood medical discipline, but astronaut workload is being further investigated to understand how the physical parameters of an EVA (terrain slope, duration, and consumables) contribute to long-duration mission planning. Artistic expression in this work is highlighted by “Performing Astronautics”, which aims to revive expeditionary artist practice in modern astronautics, exploration, and extreme performance sites. These projects were brought together through the use of common technology including biomedical devices, video and motion recording equipment, and GPS tracking. The qualitative data is maximized through the context of interdependent, layered, and complex interdisciplinary mission scenario simulations, providing higher fidelity insights into the impact and significance of the performance data in question. The simulated EVAs, survival training, and mission scenarios are opportunities to build new technology innovations to solve complex problems through an experimental process under relevant constraints. Support for human spaceflight may wax and wane and vary between nations, but with analogue missions, private or public, the crew becomes the platform themselves: implementing and expanding research data collection and capabilities by innovating within the complexity of a bootstrapped mission environment. This paper will discuss the multidiscipline approach, highlight data results from the investigations, and make recommendations for how this approach can be assimilated into exploration strategies.

Astrobiology

The Cyborg Astrobiologist: Testing a Novelty Detection Algorithm on Two Mobile Exploration Systems at Rivas Vaciamadrid in Spain and at the Mars Desert Research Station in Utah.

McGuire, P.C., Gross, C., Wendt, L., Bonnici, A., Souza-Egipsy, V., Ormö, J., Diaz-Martinez, E., Foing, B.H., Bose, R., Walter, S. and Oesker, M., **2010**. *International Journal of Astrobiology*, *9*(1), pp.11-27.

Keywords: ***MDRS***, *Astrobiology*, *geology*, *field microscope*, *wearable computer*, *systems engineering*, *novelty detection*, *Hopfield neural network*, *scientific autonomy*, *Bluetooth communications*, *phone camera*, *lichens*, *digital microscope*, *graphical programming language*, *image segmentation*, *uncommon mapping*, *Morrison Formation*, *gypsum*, *single-instance learning*

Abstract

In previous work, a platform was developed for testing computer-vision algorithms for robotic planetary exploration. This platform consisted of a digital video camera connected to a wearable computer for real-time processing of images at geological and astrobiological field sites. The real-time processing included image segmentation and the generation of interest points based upon uncommonness in the segmentation maps. Also in previous work, this platform for testing computer-vision algorithms has been ported to a more ergonomic alternative platform, consisting of a phone camera connected via the Global System for Mobile Communications (GSM) network to a remote-server computer. The wearable-computer platform has been tested at geological and astrobiological field sites in Spain (Rivas Vaciamadrid and Riba de Santiuste), and the phone camera has been tested at a geological field site in Malta. In this work, we (i) apply a Hopfield neural-network algorithm for novelty detection based upon colour, (ii) integrate a field-capable digital microscope on the wearable computer platform, (iii) test this novelty detection with the digital microscope at Rivas Vaciamadrid, (iv) develop a Bluetooth communication mode for the phone-camera platform, in order to allow access to a mobile processing computer at the field sites, and (v) test the novelty detection on the Bluetooth-enabled phone camera connected to a netbook computer at the Mars Desert Research Station in Utah. This systems engineering and field testing have together allowed us to develop a real-time computer-vision system that is capable, for example, of identifying lichens as novel within a series of images acquired in semi-arid desert environments. We acquired sequences of images of geologic outcrops in Utah and Spain consisting of various rock types and colours to test this algorithm. The algorithm robustly recognized previously observed units by their colour, while requiring only a single image or a few images to learn colours as familiar, demonstrating its fast learning capability.

Concretions in Exhumed and Inverted Channels Near Hanksville Utah: implications for Mars

Clarke, J.D. and Stoker, C.R., **2011**. *International Journal of Astrobiology*, *10*(3), pp.161-175.

Keywords: ***MDRS***, *Astrobiology*, *geology*, *Mars regolith*, *geomorphology*, *relief inversion*, *palaeochannels*, *carbonate concretions*

Abstract

The landscape near Hanksville, Utah, contains a diversity of Mars analogue features. These included segmented and inverted anastomosing palaeochannels exhumed from the Late Jurassic Brushy Basin Member of the Morrison Formation that hosts abundant small carbonate concretions. The exhumed and inverted channels closely resemble many seen on the surface of Mars in satellite imagery and

which may be visited by surface missions in the near future. The channels contain a wealth of palaeoenvironmental information and are potentially of astrobiological interest, but intrinsically difficult terrain would make their study challenging on Mars. We show that an un-exhumed channel feature can be detected geophysically, and this may allow their study in more easily accessed terrain. The concretion's morphology and surface expression parallel the haematite 'blue berries' that are strewn across the surface of Meridiani Planum on Mars. They are best developed in poorly cemented medium to coarse channel sandstones and appear to have formed during deep burial.

A Wide Variety of Putative Extremophiles and Large Beta-Diversity at the Mars Desert Research Station (Utah)

Direito, S.O., Ehrenfreund, P., Marees, A., Staats, M., Foing, B. and Röling, W.F., **2011**. *International Journal of Astrobiology*, 10(3), pp.191-207.

Keywords: ***MDRS***, *Astrobiology*, *Mars analogue*, *extremophiles* ,*alpha-diversity*, *beta-diversity*, *desert*, *DNA recovery*, *Protozoa*, *Eukarya*, *field astrobiology*

Abstract

Humankind's innate curiosity makes us wonder whether life is or was present on other planetary bodies such as Mars. The EuroGeoMars 2009 campaign was organized at the Mars Desert Research Station (MDRS) to perform multidisciplinary astrobiology research. MDRS in southeast Utah is situated in a cold arid desert with mineralogy and erosion processes comparable to those on Mars. Insight into the microbial community composition of this terrestrial Mars analogue provides essential information for the search for life on Mars: including sampling and life detection methodology optimization and what kind of organisms to expect. Soil samples were collected from different locations. Culture-independent molecular analyses directed at ribosomal RNA genes revealed the presence of all three domains of life (Archaea, Bacteria and Eukarya), but these were not detected in all samples. Spiking experiments revealed that this appears to relate to low DNA recovery, due to adsorption or degradation. Bacteria were most frequently detected and showed high alpha- and beta-diversity. Members of the *Actinobacteria*, *Proteobacteria*, *Bacteroidetes* and *Gemmatimonadetes* phyla were found in the majority of samples. Archaea alpha- and beta-diversity was very low. For Eukarya, a diverse range of organisms was identified, such as fungi, green algae and several phyla of Protozoa. Phylogenetic analysis revealed an extraordinary variety of putative extremophiles, mainly Bacteria but also Archaea and Eukarya. These comprised radioresistant, endolithic, chasmolithic, xerophilic, hypolithic, thermophilic, thermoacidophilic, psychrophilic, halophilic, haloalkaliphilic and alkaliphilic micro-organisms. Overall, our data revealed large difference in occurrence and diversity over short distances, indicating the need for high-sampling frequency at similar sites. DNA extraction methods need to be optimized to improve extraction efficiencies.

Astrobiology and Habitability Studies in Preparation for Future Mars Missions: Trends from Investigating Minerals, Organics and Biota

Ehrenfreund, P., Röling, W.F.M., Thiel, C.S., Quinn, R., Sephton, M.A., Stoker, C., Kotler, J.M., Direito, S.O.L., Martins, Z., Orzechowska, G.E. and Kidd, R.D., **2011**. *International Journal of Astrobiology*, *10*(3), pp.239-253

Keywords: ***MDRS***, *Astrobiology*, *habitability*, *life detection*, *field analogue research*, *Mars*, *organics*, *clays*, *landing site criteria*, *putative extremophiles*, *biomarkers*

Abstract

Several robotic exploration missions will travel to Mars during this decade to investigate habitability and the possible presence of life. Field research at Mars analogue sites such as desert environments can provide important constraints for instrument calibration, landing site strategies and expected life detection targets. We have characterized the mineralogy, organic chemistry and microbiology of ten selected sample sites from the Utah desert in close vicinity to the Mars Desert Research Station (MDRS) during the EuroGeoMars 2009 campaign (organized by International Lunar Exploration Working Group (ILEWG), NASA Ames and ESA ESTEC). Compared with extremely arid deserts (such as the Atacama), organic and biological materials can be identified in a larger number of samples and subsequently be used to perform correlation studies. Among the important findings of this field research campaign are the diversity in the mineralogical composition of soil samples even when collected in close proximity, the low abundances of detectable polycyclic aromatic hydrocarbons (PAHs) and amino acids and the presence of biota of all three domains of life with significant heterogeneity. An extraordinary variety of putative extremophiles, mainly Bacteria and also Archaea and Eukarya was observed. The dominant factor in measurable bacterial abundance seems to be soil porosity and lower small (clay-sized) particle content. However, correlations between many measured parameters are difficult to establish. Field research conducted during the EuroGeoMars 2009 campaign shows that the geological history and depositional environment of the region, as well as the mineralogy influence the ability to detect compounds such as amino acids and DNA. Clays are known to strongly absorb and bind organic molecules often preventing extraction by even sophisticated laboratory methods. Our results indicate the need for further development and optimization of extraction procedures that release biological compounds from host matrices to enable the effective detection of biomarkers during future sampling campaigns on Earth and Mars.

Astrobiology Field Research in Moon/Mars Analogue Environments: Instruments and Methods

Foing, B.H., Stoker, C., Zavaleta, J., Ehrenfreund, P., Thiel, C., Sarrazin, P., Blake, D., Page, J., Pletser, V., Hendrikse, J. and Direito, S., **2011**. *International Journal of Astrobiology*, 10(3), pp.141-160.

Keywords: ***MDRS***, *Astrobiology*, *Mars*, *Moon*, *instruments*, *exploration*, *technology*, *samples*, *minerals*, *organics*, *volatiles*, *biota*, *endoliths*, *EuroGeoMars*, *field research*, *XRD*, *XRF*, *in-situ analysis*

Abstract

We describe the field demonstration of astrobiology instruments and research methods conducted in and from the Mars Desert Research Station (MDRS) in Utah during the EuroGeoMars campaign 2009 coordinated by ILEWG, ESA/ESTEC and NASA Ames, with the contribution of academic partners. We discuss the entire experimental approach from determining the geological context using remote sensing, *in situ* measurements, sorties with sample collection and characterization, analysis in the field laboratory, to the post sample analysis using advanced laboratory facilities.

We present the rationale for terrestrial field campaigns to strengthen astrobiology research and the link between *in situ* and orbital remote sensing data. These campaigns are supporting the preparation for future missions such as Mars Science Laboratory, ExoMars or Mars Sample Return. We describe the EuroGeoMars 2009 campaign conducted by MDRS crew 76 and 77, focused on the investigation of surface processes in their geological context. Special emphasis was placed on sample collection and pre-screening using *in-situ* portable instruments. Science investigations included geological and geochemical measurements as well as detection and diagnostic of water, oxidants, organic matter, minerals, volatiles and biota.

EuroGeoMars 2009 was an example of a Moon–Mars field research campaign dedicated to the demonstration of astrobiology instruments and a specific methodology of comprehensive measurements from selected sampling sites. We discuss in sequence: the campaign objectives and trade-off based on science, technical or operational constraints. This includes remote sensing data and maps, and geological context; the monitoring of environmental parameters; the geophysical context and mineralogy studies; geology and geomorphology investigations; geochemistry characterization and subsurface studies. We describe sample handling (extraction and collection) methods, and the sample analysis of soils and rocks performed in the MDRS laboratory using close inspection, initial petrological characterization, microscopy, Visible-NIR spectrometry, Raman spectrometry, X-ray diffraction/X-ray fluorescence spectrometry, soil analysis, electrochemical and biological measurements.

The results from post-mission analysis of returned samples using advanced facilities in collaborator institutes are described in companion papers in this issue. We present examples of *in-situ* analysis, and describe an example investigation on the exploration and analysis of endolithic microbial mats (from reconnaissance, *in-situ* imaging, sampling, local analysis to post-mission sample analysis).

Analysis of Mineral Matrices of Planetary Soil Analogues from the Utah Desert

Kotler, J.M., Quinn, R.C., Foing, B.H., Martins, Z. and Ehrenfreund, P., **2011**. *International Journal of Astrobiology*, 10(3), pp.221-229.

Keywords: ***MDRS***, *Astrobiology*, *planetary geology*, *mineralogy*, *clay minerals*, *phllosilicates*, *hydrated sulphate minerals*, *EuroGeoMars*, *XRD*, *FTIR*.

Abstract

Phyllosilicate minerals and hydrated sulphate minerals have been positively identified on the surface of Mars. Studies conducted on Earth indicate that micro-organisms influence various geochemical and mineralogical transitions for the sulphate and phyllosilicate minerals. These minerals in turn provide key nutrients to micro-organisms and influence microbial ecology. Therefore, the presence of these minerals in astrobiology studies of Earth–Mars analogue environments could help scientists better understand the types and potential abundance of micro-organisms and/or biosignatures that may be encountered on Mars. Bulk X-ray diffraction of samples collected during the EuroGeoMars 2009 campaign from the Mancos Shale, the Morrison and the Dakota formations near the Mars Desert Research Station in Utah show variable but common sedimentary mineralogy with all samples containing quantities of hydrated sulphate minerals and/or phyllosilicates. Analysis of the clay fractions indicate that the phyllosilicates are interstratified illite–smectites with all samples showing marked changes in the diffraction pattern after ethylene glycol treatment and the characteristic appearance of a solvated peak at ~17 Å. The smectite phases were identified as montmorillonite and nontronite using a combination of the X-ray diffraction data and Fourier–Transform Infrared Spectroscopy. The most common sulphate mineral in the samples is hydrated calcium sulphate (gypsum), although one sample contained detectable amounts of strontium sulphate (celestine). Carbonates detected in the samples are variable in composition and include pure calcium carbonate

(calcite), magnesium-bearing calcium carbonate (dolomite), magnesium, iron and manganese-bearing calcium carbonate (ankerite) and iron carbonate (siderite). The results of these analyses when combined with organic extractions and biological analysis should help astrobiologists and planetary geologists better understand the potential relationships between mineralogy and microbiology for planetary missions.

Extraction of Amino Acids from Soils Close to the Mars Desert Research Station (MDRS), Utah

Martins, Z., Sephton, M.A., Foing, B.H. and Ehrenfreund, P., **2011**. *International Journal of Astrobiology*, *10*(3), pp.231-238.

Keywords: ***MDRS***, *Astrobiology*, *amino acids*, *Mars analogue soils*, *EuroGeoMars*, *life detection*, *field sampling*, *geology*, *mineralogy*, *bio-signatures.*

Abstract

Future space missions that aim to detect life should search for molecules that are vital to all living organisms. Although the Viking landers did not find any signs of organic molecules on Mars, signatures of past and/or present life may still exist in the Martian regolith. In this paper, we describe amino acid analyses performed in several Martian analogue soil samples collected close to the Mars Desert Research Station (MDRS), Utah, during the International Lunar Exploration Working Group (ILEWG) EuroGeoMars campaign in February 2009. The Utah desert around Hanksville is characterized as shale desert and is cold and arid with an average annual temperature of 12°C. It is subjected to wind erosion and was shaped by fluvial erosion. The data show large differences in the total amino acid abundances between all the collected soil samples, with values ranging from non-detectable to 100 000 parts per billion (ppb). These results are explained in the context of mineralogical differences (namely different clay content) among the soil samples. The data have implications for future life-detection missions and the target mineralogy that may host biological signatures.

Analysis of Mars Analogue Soil Samples Using Solid-Phase Microextraction, Organic Solvent Extraction and Gas Chromatography/Mass Spectrometry

Orzechowska, G.E., Kidd, R.D., Foing, B.H., Kanik, I., Stoker, C. and Ehrenfreund, P., **2011**. *International Journal of Astrobiology*, *10*(3), pp.209-219.

Keywords: ***MDRS***, *Astrobiology*, *geology*, *chromatography*, *gas chromatograph/mass spectrometer (GC/MS)*, *Mars*, *polycyclic aromatic hydrocarbons (PAHs)*, *solid-phase microextraction (SPME)*, *soil samples*, *liquid extraction*, *planetary exploration*

Abstract

Polycyclic aromatic hydrocarbons (PAHs) are robust and abundant molecules in extraterrestrial environments. They are found ubiquitously in the interstellar medium and have been identified in extracts of meteorites collected on Earth. PAHs are important target molecules for planetary exploration missions that investigate the organic inventory of planets, moons and small bodies. This study is part of an interdisciplinary preparation phase to search for organic molecules and life on Mars. We have investigated PAH compounds in desert soils to determine their composition, distribution and stability. Soil samples (Mars analogue soils) were collected at desert areas of Utah in the vicinity of the Mars Desert Research Station (MDRS), in the Arequipa region in Peru and from the Jutland region of Denmark. The aim of this study was to optimize the solid-phase microextraction (SPME) method for

fast screening and determination of PAHs in soil samples. This method minimizes sample handling and preserves the chemical integrity of the sample. Complementary liquid extraction was used to obtain information on five- and six-ring PAH compounds. The measured concentrations of PAHs are, in general, very low, ranging from 1 to 60 ng g^{-1}. The texture of soils is mostly sandy loam with few samples being 100 % silt. Collected soils are moderately basic with pH values of 8–9 except for the Salten Skov soil, which is slightly acidic. Although the diverse and variable microbial populations of the samples at the sample sites might have affected the levels and variety of PAHs detected, SPME appears to be a rapid, viable field sampling technique with implications for use on planetary missions.

Mineralogical, Chemical, Organic and Microbial Properties of Subsurface Soil Cores from Mars Desert Research Station (Utah, USA): Phyllosilicate and Sulfate Analogues to Mars Mission Landing Sites.

Stoker, C.R., Clarke, J., Direito, S.O., Blake, D., Martin, K.R., Zavaleta, J. and Foing, B., **2011**., *International Journal of Astrobiology*, *10*(3), pp.269-289.

Keywords: ***MDRS***, *Astrobiology*, *geology*, *Mars Science Lander*, *CheMin instrument*, *clay minerals*, *organics*, *subsurface biology*, *soluble ion chemistry*, *microbial populations*, *XRD*, *soil chemistry*

Abstract

We collected and analysed soil cores from four geologic units surrounding Mars Desert Research Station (MDRS) Utah, USA, including Mancos Shale, Dakota Sandstone, Morrison formation (Brushy Basin member) and Summerville formation. The area is an important geochemical and morphological analogue to terrains on Mars. Soils were analysed for mineralogy by a Terra X-ray diffractometer (XRD), a field version of the CheMin instrument on the Mars Science Laboratory (MSL) mission (2012 landing). Soluble ion chemistry, total organic content and identity and distribution of microbial populations were also determined. The Terra data reveal that Mancos and Morrison soils are rich in phyllosilicates similar to those observed on Mars from orbital measurements (montmorillonite, nontronite and illite). Evaporite minerals observed include gypsum, thenardite, polyhalite and calcite. Soil chemical analysis shows sulfate the dominant anion in all soils and SO_4>>CO_3, as on Mars. The cation pattern Na>Ca>Mg is seen in all soils except for the Summerville where Ca>Na. In all soils, SO_4 correlates with Na, suggesting sodium sulfates are the dominant phase. Oxidizable organics are low in all soils and range from a high of 0.7% in the Mancos samples to undetectable at a detection limit of 0.1% in the Morrison soils. Minerals rich in chromium and vanadium were identified in Morrison soils that result from diagenetic replacement of organic compounds. Depositional environment, geologic history and mineralogy all affect the ability to preserve and detect organic compounds. Subsurface biosphere populations were revealed to contain organisms from all three domains (Archaea, Bacteria and Eukarya) with cell density between 3.0×10^6 and 1.8×10^7 cells ml^{-1} at the deepest depth. These measurements are analogous to data that could be obtained on future robotic or human Mars missions and results are relevant to the MSL mission that will investigate phyllosilicates on Mars.

Human Crew-Related Aspects for Astrobiology Research

Thiel, C.S., Pletser, V. and Foing, B., **2011**. *International Journal of Astrobiology*, *10*(3), pp.255-267.

Keywords: ***MDRS***, *Astrobiology*, *PCR instrumentation for life detection*, *human factors*, *EuroGeoMars*, *geology*, *biology*, *astronomy/astrophysics*, *technology*, *social*, *operational aspects*, *habitat laboratory*.

Abstract

Several space agencies and exploration stakeholders have a strong interest in obtaining information on technical and human aspects to prepare for future extra-terrestrial planetary exploration. In this context, the EuroGeoMars campaign, organized with support from the International Lunar Exploration Working Group (ILEWG), the European Space Agency (ESA), the National Aeronautics and Space Administration (NASA) Ames Research Center and partner institutes, was conducted by the crews 76 and 77 in February 2009 in The Mars Society's 'Mars Desert Research Station' (MDRS) in Utah.
The EuroGeoMars encompasses two groups of experiments: (1) a series of field science experiments that can be conducted from an extra-terrestrial planetary surface in geology, biology, astronomy/astrophysics and the necessary technology and networks to support these field investigations; (2) a series of human crew-related investigations on crew time organization in a planetary habitat, on the different functions and interfaces of this habitat, and on man–machine interfaces of science and technical equipment.
This paper recalls the objective of the EuroGeoMars project and presents the MDRS and its habitat layout. Social and operational aspects during simulations are described. Technical and operational aspects of biology investigations in the field and in the habitat laboratory are discussed in detail with the focus point set on the polymerase chain reaction (PCR)-based detection of microbial DNA in soil samples.

PCR-Based Analysis of Microbial Communities During the EuroGeoMars Campaign at Mars Desert Research Station, Utah

Thiel, C.S., Ehrenfreund, P., Foing, B., Pletser, V. and Ullrich, O., **2011**. *International Journal of Astrobiology*, *10*(3), pp.177-190.

Keywords: ***MDRS***, *Astrobiology*, *microbial communities*, *PCR instrumentation*, *ribosomal DNA*, *EuroGeoMars*

Abstract

The search for evidence of past or present life on Mars will require the detection of markers that indicate the presence of life. Because deoxyribonucleic acid (DNA) is found in all known living organisms, it is considered to be a 'biosignature' of life. The main function of DNA is the long-term storage of genetic information, which is passed on from generation to generation as hereditary material. The Polymerase Chain Reaction (PCR) is a revolutionary technique which allows a single fragment or a small number of fragments of a DNA molecule to be amplified millions of times, making it possible to detect minimal traces of DNA. The compactness of the contemporary PCR instruments makes routine sample analysis possible with a minimum amount of laboratory space. Furthermore the technique is effective, robust and straightforward. Our goal was to establish a routine for the detection of DNA from micro-organisms using the PCR technique during the EuroGeoMars simulation campaign. This took place at the Mars Society's Mars Desert Research Station (MDRS) in Utah in February 2009 (organized with the support of the International Lunar Exploration Working Group (ILEWG), NASA Ames and the European Space Research and Technology Centre (ESTEC)). During the MDRS simulation, we showed that it is possible to establish a minimal molecular biology lab in the habitat for the

immediate on-site analysis of samples by PCR after sample collection. Soil and water samples were taken at different locations and soil depths. The sample analysis was started immediately after the crew returned to the habitat laboratory. DNA was isolated from micro-organisms and used as a template for PCR analysis of the highly conserved ribosomal DNA to identify representatives of the different groups of micro-organisms (bacteria, archaea and eukarya). The PCR products were visualized by agarose gel electrophoresis and documented by transillumination and digital imaging. The microbial diversity in the collected samples was analysed with respect to sampling depth and the presence or absence of vegetation. For the first time, we have demonstrated that it is possible to perform direct on-site DNA analysis by PCR at MDRS, a simulated planetary habitat in an extreme environment that serves as a model for preparation and optimization of techniques to be used for future Mars exploration.

Extreme Niche Partitioning and Microbial Dark Matter in a Mauna Loa Lava Tube

Fishman, C.B., Bevilacqua, J.G., Hahn, A.S., Morgan Lang, C., Wagner, N., Gadson, O., McAdam, A.C., Bleacher, J., Achilles, C., Knudson, C. and Millan, M.M., **2023**, *Journal of Geophysical Research: Planets*, p.e2022JE007283.

Keywords: ***HI-SEAS***, *Astrobiology*, *geology*, *microbiology*, *16S SSU rRNA sequencing*, *lava tubes*, *bio-signatures*, *life detection*, *niche partitioning*, *bioinformatics*, *metagenomics*

Abstract

Lava tubes are key targets in the search for life on Mars. Their basaltic walls provide protection from radiation and changing environmental conditions, which could enable life or preservation of previous life in an otherwise harsh environment. We can understand the potential for Martian life in lava tubes by studying the habitability of analog environments on Earth. In this study, we present the first characterization of the microbial life inside a pristine Mauna Loa lava tube. This study is the first to combine 16S SSU rRNA sequencing and whole genome shotgun sequencing to map the taxonomic makeup and functional potential of any lava tube community in Hawaii, enabling a deep understanding of the types of microbes that thrive in this unique environment and the metabolisms they use. We find a surprisingly high degree of niche partitioning over small spatial scales and discuss implications for life detection strategies. Based on recent bioinformatic advancements in metagenomics, we also assemble dozens of high-quality metagenome assembled genomes from the microbes living in the lava tubes, including several novel species.

Desert Botany

The "Martian" Flora: New Collections Of Vascular Plants, Lichens, Fungi, Algae, and Cyanobacteria from the Mars Desert Research Station, Utah

Sokoloff, P.C., Freebury, C.E., Hamilton, P.B. and Saarela, J.M., **2016**. *Biodiversity Data Journal*, (4).

Keywords: ***MDRS***, *Desert Botany*, *floristics*, *lichen*, *algae*, *endolithic chlorophytes*, *cyanobacteria*, *vascular plants*, *fungi*

Abstract

The Mars Desert Research Station is a Mars analog research site located in the desert outside of Hanksville, Utah, U.S.A. Here we present a preliminary checklist of the vascular plant and lichen flora for the station, based on collections made primarily during a two-week simulated Mars mission in November, 2014. Additionally, we present notes on the endolithic chlorophytes and cyanobacteria, and the identification of a fungal genus also based on these collections. Altogether, we recorded 38 vascular plant species from 14 families, 13 lichen species from seven families, six algae taxa including both chlorophytes and cyanobacteria, and one fungal genus from the station and surrounding area. We discuss this floristic diversity in the context of the ecology of the nearby San Rafael Swell and the desert areas of Wayne and Emery counties in Southeastern Utah.

Additions to the “Martian Flora”: New Botanical Records from the Mars Desert Research Station, Utah

Sokoloff, P.C., Murray, D.A., McBeth, S.R., Irvine, M.G. and Rupert, S.M., **2020**. *Biodiversity Data Journal*, *8*.

Keywords: ***MDRS***, *Desert Botany*, *floristics*, , *lichen*, *algae*, *endolithic chlorophytes*, *cyanobacteria*, *vascular plants*, *fungi*

Abstract

The Mars Desert Research Station (MDRS) is a Mars-simulation campus set in a Martian planetary analogue in southern Utah. Despite a long history of astrobiology research, collections-based taxonomic inventories of the macro-level biodiversity around the station are relatively new. This study serves to add to the initial vascular plant list published for the station in 2016, where 39 species were recorded for MDRS. Here we report 40 new species, two new taxa recorded only to genus and two species re-identified from our 2016 fieldwork, bringing the total number of taxa in the "Martian" flora to 79 species and two taxa recorded to genus.

Emergency Medical Interventions

Planetary Analogues EVA Medical Emergency Simulations: Transportation Methods

Diaz, A., Scheuring, R.A., Moïn-Darbari, K.A., Manyapu, K.K., Medley, M.D., Calderon, F. and Groemer, G., **2013**. In *43rd International Conference on Environmental Systems* (p. 3507).

Keywords: ***MDRS***, *Emergency medical interventions*, *emergency simulations*, *EVA medical situations*

Abstract

Future NASA planetary exploration will call for extended human presence in space, with long term missions to the Moon, Mars, and/or asteroids. This human presence in extraterrestrial locations will require use of planetary surface Extra-Vehicular Activities (EVAs), which will involve inherently dangerous procedures that can put crew safety at risk. One need only peruse proposed EVA operations for future planetary surface missions to understand the risks astronauts will be exposed to. These EVAs will include activities such as base construction, base operation and maintenance, emergency and safety procedures, planetary surface exploration, planetary surface science, robotic operation and maintenance, and in-situ resource utilization (ISRU) operations. To help mitigate EVA medical risks, astronaut training programs will spend substantial attention on preparing for planetary surface EVA emergencies. To this end, the Mars Desert Research Station (MDRS) and Haughton Mars Project (HMP) provide excellent analogues to perform simulated planetary EVA emergencies. These stations are a platform for aerospace medical research investigating the complexities of medical rescue operations in a remote and hostile setting.

Several MDRS crew rotations have performed EVA emergency simulations. During these simulations, the ability of crewmembers to act quickly and effectively in emergency medical situations in analogue environments was assessed. General results from these simulations yielded issues concerning medical care provisions, constraints in care due to spacesuits, and time delay during real emergencies. This paper summarizes these EVA emergency simulations, provides recommendations, and identifies future areas of research.

Intubation After Rapid Sequence Induction Performed by Non-Medical Personnel During Space Exploration Missions: A Simulation Pilot Study in a Mars Analogue Environment

Komorowski, M. and Fleming, S., **2015**. *Extreme physiology & medicine*, *4*, pp.1-10.

Keywords: ***MDRS***, *Emergency medicine*, *oro-tracheal intubation*, *general anaesthesia*, *space medicine*, *training non-specialist medical personnel*

Abstract

BACKGROUND:The question of the safety of anaesthetic procedures performed by non anaesthetists or even by non physicians has long been debated. We explore here this question in the hypothetical context of an exploration mission to Mars. During future interplanetary space missions, the risk of medical conditions requiring surgery and anaesthetic techniques will be significant. On Earth, anaesthesia is generally performed by well accustomed personnel. During exploration missions, onboard medical expertise might be lacking, or the crew doctor could become ill or injured. Telemedical assistance will not be available. In these conditions and as a last resort, personnel with limited medical training may have to perform lifesaving procedures, which could include anaesthesia and surgery. The objective of this pilot study was to test the ability for unassisted personnel with no

medical training to perform oro-tracheal intubation after a rapid sequence induction on a simulated deconditioned astronaut in a Mars analogue environment. The experiment made use of a hybrid simulation model, in which the injured astronaut was represented by a torso manikin, whose vital signs and hemodynamic status were emulated using a patient simulator software. Only assisted by an interactive computer tool (PowerPoint® presentation), five participants with no previous medical training completed a simplified induction of general anaesthesia with intubation.
RESULTS: No major complication occurred during the simulated trials, namely no cardiac arrest, no hypoxia, no cardiovascular collapse and no failure to intubate. The study design was able to reproduce many of the constraints of a space exploration mission.
CONCLUSIONS: Unassisted personnel with minimal medical training and familiarization with the equipment may be able to perform advanced medical care in a safe and efficient manner. Further studies integrating this protocol into a complete anaesthetic and surgical scenario will provide valuable input in designing health support systems for space exploration missions.

3D Printed Surgical Instruments Evaluated by a Simulated Crew of a Mars Mission

Wong, J.Y. and Pfahnl, A.C., **2016**. *Aerospace medicine and human performance*, *87*(9), pp.806-810.

Keywords: ***HI-SEAS***, *emergency medicine*, *digital fabrication*, *additive manufacturing*, *space medicine*, *surgery*, *fused deposition modeling*, *space mission surgery*, *3D printing*.

Abstract

INTRODUCTION: The first space-based fused deposition modeling (FDM) 3D printer became operational in 2014. This study evaluated whether Mars simulation crewmembers of the Hawai'i Space Exploration Analog and Simulation (HI-SEAS) II mission with no prior surgical experience could utilize acrylonitrile butadiene styrene (ABS) thermoplastic surgical instruments FDM 3D printed on Earth to complete simulated surgical tasks.
METHODS: This study sought to examine the feasibility of using 3D printed surgical tools when the primary crew medical officer is incapacitated and the back-up crew medical officer must conduct a surgical procedure during a simulated extended space mission. During a 4 mo duration ground-based analog mission, five simulation crewmembers with no prior surgical experience completed 16 timed sets of simulated prepping, draping, incising, and suturing tasks to evaluate the relative speed of using four ABS thermoplastic instruments printed on Earth compared to conventional instruments.
RESULTS: All four simulated surgical tasks were successfully performed using 3D printed instruments by Mars simulation crewmembers with no prior surgical experience. There was no substantial difference in time to completion of simulated tasks with control vs. 3D printed sponge stick, towel clamp, scalpel handle, and toothed forceps.
DISCUSSION: These limited findings support further investigation into the creation of an onboard digital catalog of validated 3D printable surgical instrument design files to support autonomous, crew-administered healthcare on Mars missions. Future work could include addressing sterility, biocompatibility, and having astronaut crew medical officers test a wider range of surgical instruments printed in microgravity during actual surgical procedures.

Mechanical Design of a Novel Surgical Laparoscopic Simulator for Telemedicine Assistance and Physician Training during Aerospace Applications

Cornejo, J., Cornejo-Aguilar, J.A., Sebastian, R., Perales, P., Gonzalez, C., Vargas, M. and Elli, E.F., **2021**, In *2021 IEEE 3rd Eurasia Conference on Biomedical Engineering, Healthcare and Sustainability (ECBIOS)* (pp. 53-56).

Keywords: ***MDRS***, *Emergency medicine, medical robot, multi-DOF system, telemedicine, human factors, surgical training*

Abstract

Surgery in space requires enhancing the user's skills under the expert physician's remote guidance. Therefore, the Surgical Engineering Society, with Bioastronautics and Space Mechatronics Research Group have worked on a collaborative study from 2020 to 2021, resulting in the proposed project named "SP-LAP" which is a Medical Robot, defined as a Surgical Laparoscopic Simulation Platform integrated with multi-degree-of-freedom (multi-DOF) system. The analysis is focused on the mechanical design, telemedicine assistance, surgical training and human factors, considering aerospace engineering fundamentals. It has been chosen to evaluate the surgical performance and to develop the technical-clinical validation tests at Mars Analog Desert.

An Easy-To-Use External Fixator for All Hostile Environments, from Space to War Medicine: Is It Meant for Everyone's Hands?

Manon, J., Pletser, V., Saint-Guillain, M., Vanderdonckt, J., Wain, C., Jacobs, J., Comein, A., Drouet, S., Meert, J., Sanchez Casla, I.J. and Cartiaux, O., **2023**. *Journal of clinical medicine*, *12*(14), p.4764.

Keywords: ***MDRS***, *Emergency Medicine, tibial shaft fracture; external fixator; hostile environments; learning curve; space medicine; developing countries; war medicine, training non-specialist medical personnel*

Abstract

Long bone fractures in hostile environments pose unique challenges due to limited resources, restricted access to healthcare facilities, and absence of surgical expertise. While external fixation has shown promise, the availability of trained surgeons is limited, and the procedure may frighten unexperienced personnel. Therefore, an easy-to-use external fixator (EZExFix) that can be performed by nonsurgeon individuals could provide timely and life-saving treatment in hostile environments; however, its efficacy and accuracy remain to be demonstrated. This study tested the learning curve and surgical performance of nonsurgeon analog astronauts (n = 6) in managing tibial shaft fractures by the EZExFix during a simulated Mars inhabited mission, at the Mars Desert Research Station (Hanksville, UT, USA). The reduction was achievable in the different 3D axis, although rotational reductions were more challenging. Astronauts reached similar bone-to-bone contact compared to the surgical control, indicating potential for successful fracture healing. The learning curve was not significant within the limited timeframe of the study (N = 4 surgeries lasting <1 h), but the performance was similar to surgical control. The results of this study could have important implications for fracture treatment in challenging or hostile conditions on Earth, such as war or natural disaster zones, developing countries, or settings with limited resources.

Energy

Mars Habitat Power Consumption Constraints, Prioritization, and Optimization

Barnard, A., Engler, S.T. and Binsted, K., **2019**. *Journal of Space Safety Engineering*, *6*(4), pp.256-264.

Keywords: ***HI-SEAS***, *Energy*, *Power consumption*, *power budget profiles*, *low power constraints*, *optimization methods*, *power audits*

Abstract

The Hawai'i Space Exploration Analog and Simulation (HI-SEAS) is an experiment simulating long-duration life in a Mars habitat. Power for the habitat is generated by a photovoltaic system that exhibits daily variation in production rates. During days with cloud cover, the crew need to adapt their work schedule and support systems to ensure they can continue to function under low-power constraints. This paper accordingly presents the development and implementation of power budget profiles for low-, medium-, and high-power production days during Mission 5 of the HI-SEAS experiment. The applied power budget profiles limit which systems and devices can be used and for what duration. To generate these profiles, the HI-SEAS power subsystem was first characterized though power audits and data from daily crew use trends. The methods used to determine a prioritized list of habitat equipment for crew-member usage and compliance with restrictions are then discussed. Finally, an optimization method is proposed to determine the most efficient schedule to match each power usage profile with respect to crew preferences. The data from this experiment provide a novel opportunity to gain insight into power usage in space exploration habitats, establishing a foundation for the development of proper power generation and management technologies. Thus, this research can be used to provide meaningful guidance to most manned space systems in ensuring optimal power consumption under a variety of power generation conditions.

HI-SEAS Habitat Energy Requirements and Forecasting

Engler, S.T., Binsted, K. and Leung, H., **2019**. *Acta Astronautica*, *162*, pp.50-55.

Keywords: ***HI-SEAS***, *Energy*, *Analog*, *Simulation*, *Manned missions*, *Machine learning*, *energy forecasting*, *LSS*, *human factors*

Abstract

Travel to other planetary bodies represents a major challenge to resource management. Previous manned exploration missions of long duration have been resupplied with food, water, and air as required. Manned missions to other planetary bodies will have durations of years with little to no possibility of resupply. Consequently, monitoring and forecasting resource consumption are mission-critical capabilities. The Hawaii Space Exploration Analog and Simulation, a long-duration planetary analog simulation, has recently completed its fifth long-term isolation mission conducted to assess the energy, food, and water needs of a six-person long-term planetary mission. This study presents a novel method for forecasting energy consumption, which incorporates the emotional state of the habitat crew. Gathered data show inhabitants in small environments can be influenced considerably by the actions of a single member. This can result in dramatic changes in consumption that could cause forecasting models to deviate to the point of total failure. Previous work found that inclusion of the daily activities and the psychological states of the crew allows for higher accuracy in long-duration forecasts. Currently, psychological assessments in the form of a Positive and Negative Affect Schedule and a generalized artificial neural modulation method are used to incorporate emotional response into machine learning forecast methods. Using these techniques and developments, a large-scale

smart habitat control and forecasting system is proposed that will monitor, control, and forecast HI-SEAS habitat resources for future HI-SEAS missions. This new system requires the incorporation of psychological and physiological data of the crew, together with information on their activities and schedules.

Internal Heat Loads in LUNARES Analogue Planetary Base - a Case Study

Kaczmarzyk, M. and Waśniowski, A., **2019**. *Journal of Civil Engineering, Environment and Architecture*.

Keywords: ***LunAres***, *Energy, space building physics, internal heat loads and gains, analogue space station, metabolic heat generation, heat load prediction, planetary bases*

Abstract

This case study work focuses on recognising and quantifying internal heat sources in the first European analogue planetary base: the recently constructed Polish LunAreS habitat. The paper explains the necessity of conducting analogue space missions prior to an actual manned exploration of the Moon and Mars. Notions of internal heat loads and gains have been elaborated along with their significance for developing space building physics. This paper presents the results of thorough inspection of all internal heat sources, conducted by one of the authors during ICAres-1 Mars analogue mission aboard the LUNARES base. Three main sources of internal heat loads were identified and carefully studied; the habitat's electrical equipment, the crew body heat and their personal appliances. These heat loads were calculated and total internal heat load of the base was established and discussed. The results of this study may serve as a baseline for predicting internal heat loads aboard actual planetary bases.

Internal Heat Gains in a Lunar Base - A Contemporary Case Study

Kaczmarzyk, M., Starakiewicz, A. and Waśniowski, A., **2020**. *Energies*, *13*(12), p.3213.

Keywords: LunAres, Energy, extra-terrestrial building physics, internal heat gain, energy storage, occupational heat load, analogue planetary base, waste heat, LSS

Abstract

The Moon's environmental conditions present limited opportunities for waste heat dissipation, so internal heat gains (IHG) are a key component of thermal balance in a lunar building. Despite the significant development in energy saving and energy storage technologies of the last thirty years, the issue of IHG in lunar buildings has not been readdressed since the early 1990s. This study is based on an inspection of internal heat sources conducted aboard LUNARES, the first European extraterrestrial analogue habitat. The equipment absent on LUNARES, but indispensable for an actual lunar base, was identified and accounted for, along with additional laboratory and maintenance equipment. Three main groups of internal heat sources were identified and studied in detail. Waste heat generated by electric devices was accounted for, along with occupational heat loads adjusted for lunar partial gravity conditions. Assuming a photovoltaic power source for the studied building, two alternative energy storage systems (ESS) were analysed as another source of waste heat. Depending on the time of lunar day and applied ESS, the nominal IHG were between 73 and 133 W/m^2. The most significant internal heat sources in a lunar base are life support systems and potentially, regenerative fuel cells; thus, lithium–ion batteries were recommended for ESS. Within assumed parameter range, parametric study exhibited differences in IHG between 41.5 and 163 W/m^2.

Parametric Study of a Lunar Base Power Systems

Kaczmarzyk, M. and Musiał, M., **2021**. *Energies*, *14*(4), p.1141.

Keywords: ***LunAres***, *Energy*, *extra-terrestrial building physics*, *power system*, *energy storage*, *lunar base*, *photovoltaics*, *nuclear reactor*, *Selenographic latitude*, *solar illumination*, *temperature control*, *hybrid power systems*

Abstract

Due to the extreme cost of cargo transportation from Earth to the lunar surface, future lunar base subsystems are required to be rigorously optimized in terms of mass reduction. The purpose of this paper was to identify and evaluate the influence of key parameters of proposed lunar base power systems, as well as of the lunar environment on the total power system mass. Nine different power systems were studied as combinations of two power sources and three energy storage technologies. Power system architecture, total power demand of the base, its power management strategy, solar array structure type, Selenographic latitude and solar illumination conditions were nominated as the primary parameters for this study. Total power system mass calculations were performed for more than 200 combinations of these parameters, including three separate case studies. The total mass calculated for each combination included a power source, an energy storage unit, temperature control and the balance of system. For the wide range of studied parameters, hybrid power systems that combine solar and nuclear power were found to be the most advantageous solutions in terms of mass reduction.

Extra-Vehicular Activity

Surface Extra-Vehicular Activity Emergency Scenario Management: Tools, Procedures, and Geologically Related Implications

Zea, L., Diaz, A.R., Shepherd, C.K. and Kumar, R., **2010**. *Acta Astronautica*, *67*(1-2), pp.60-70.

Keywords: ***MDRS***, *EVAs*, *emergency situations*, *life support systems*, *LSS*, *astronaut training*, *crew training*, *mobility*, *geology*, *EVA protocols*, *emergency stretcher*, *suit malfunction*, *medical issues*

Abstract

Extra-vehicular activities (EVAs) are an essential part of human space exploration, but involve inherently dangerous procedures which can put crew safety at risk during a space mission. To help mitigate this risk, astronauts' training programs spend substantial attention on preparing for surface EVA emergency scenarios. With the help of two Mars Desert Research Station (MDRS) crews (61 and 65), wearing simulated spacesuits, the most important of these emergency scenarios were examined at three different types of locations that geologically and environmentally resemble lunar and Martian landscapes. These three platforms were analyzed geologically as well as topographically (utilizing a laser range finder with slope estimation capabilities and a slope determination software). Emergency scenarios were separated into four main groups: (1) suit issues, (2) general physiological, (3) attacks and (4) others. Specific tools and procedures were developed to address each scenario. The tools and processes were tested in the field under Mars-analog conditions with the suited subjects for feasibility and speed of execution.

Ergonomy of Head Mounted Displays Inside Analog Spacesuit – Mars Analog Extravehicular Activities

Doule, O., **2014**. In *AIAA SPACE 2014 conference and exposition* (p. 4406).

Keywords: ***MDRS***, *EVAs*, *spacesuit*, *space helmet*, *head mounted displays*, *HUD*, *fixed information*, *head tracking*, *navigation*, *TLX evaluation system*, *ergonomics*

Abstract

This paper summarizes an evaluation of commercially available sight peripheral information transparent head-mounted Head-Up Displays (HUD) from the user's viewpoint during Extra Vehicular Activity (EVA) exploratory tasks in simulated Mars environment. The evaluation is based on experimental use and focuses on the possibilities of safety enhancement, usability regarding visual and voice aid, affordance, usefulness, mission reliability enhancement and HUD health or technical risks. The experiment was performed at the Mars Desert Research Station (MDRS) in Utah. The tested system is composed of two types of commercially available transparent display HUDs (fixed information and head tracking), each providing time, navigation and user heart rate information. The HUDs were used during six one-hour team EVAs, each focused on a navigation tasks and various activities based on the individual EVA goals of the Crew 135 Reliability and Redundancy mission. The experiment data were post-processed/analyzed using video and sound recording by video cameras placed on arms, shoulder, or helmet and embedded in the HUD. Individual feedback is recorded through a modified NASA TLX evaluation system after each EVA, and our conclusions regarding ergonomics are summarized in table form. Hand-held and Head Mounted Displays (HMD) systems are also compared.

Need for Touch in Human Space Exploration: Towards the Design of a Morphing Haptic Glove – Exoskin

Seah, S.A., Obrist, M., Roudaut, A. and Subramanian, S., **2015**, August. In *IFIP Conference on Human-Computer Interaction* (pp. 18-36). Cham: Springer International Publishing

Keywords: ***MDRS***, *EVAs*, *Haptic feedback*, *Haptic glove*, *User experience*, *Haptic jamming*, *Field study*, *Technology probes*, *spacesuits*, *spacesuit gloves*

Abstract

The spacesuit, particularly the spacesuit glove, creates a barrier between astronauts and their environment. Motivated by the vision of facilitating full-body immersion for effortless space exploration, it is necessary to understand the sensory needs of astronauts during extra-vehicular activities (EVAs). In this paper, we present the outcomes from a two-week field study performed at the Mars Desert Research Station, a facility where crews carry out Mars-simulated missions. We used a combination of methods (a haptic logbook, technology probes, and interviews) to investigate user needs for haptic feedback in EVAs in order to inform the design of a haptic glove. Our results contradict the common belief that a haptic technology should always convey as much information as possible, but should rather offer a controllable transfer. Based on these findings, we identified two main design requirements to enhance haptic feedback through the glove: (i) transfer of the shape and pressure features of haptic information and (ii) control of the amount of haptic information. We present the implementation of these design requirements in the form of the concept and first prototype of ExoSkin. ExoSkin is a morphing haptic feedback layer that augments spacesuit gloves by controlling the transfer of haptic information from the outside world onto the astronauts' skin.

Surface Operations During a Long-Duration Mars Simulation Mission

Heinicke, C. and Verseux, C., **2017**. *Proc Int Astronaut Congr IAC*, *8*, pp.5459-64.

Keywords: ***HI-SEAS***, *EVAs*, *long-duration spaceflight*, *mission planning*, *field operations*, *lessons learned*

Abstract

Exploration and field work are the primary purposes of future scientific manned missions to another planetary body like Moon or Mars. Since the crew will know the surface of Mars and their own physical state better than anyone back on Earth, it is likely that the crew autonomously plan and organize their necessary extravehicular activities (EVAs), potentially with the help of a mission support based on Earth. However, few references exist to date for long-duration missions during which a substantial fraction of mission time is spent on EVAs. One of the longest simulation missions, HI-SEAS IV, ended in August 2016 and comprised a total number of 154 EVAs, lasting a total of 316 h. Wearing simulated space suits, the crew conducted those EVAs to fulfil four types of tasks: science, exploration, maintenance, and leisure. We will analyze the evolution of the mission EVAs over time, in particular the actual time spent outside the habitat. In addition, we will provide estimates of the time spent on the planning of EVAs. The information may serve both as a reference and guideline, for mission planners and crews of simulated and real manned planetary missions.

Advancing Extravehicular Activity (EVA) Spaceflight Operations and Education by Supporting Analogue Metrics Analysis and Developing Spacesuit Demonstrations

Lones, J. and Kobrick, R.L., **2017**. In *AIAA SPACE and Astronautics Forum and Exposition* (p. 5114).

Keywords: ***HI-SEAS***, *EVAs*, *Spacesuits*, *range of motion*, *mobility*, *hazmat suits*, *outreach*

Abstract

Spacesuits are much more than a one-person spacecraft that protects the human body against the extreme and harsh space environment, they can be an extension to human capability. Spacesuits are often used during extravehicular activities (EVAs) where astronauts perform tasks outside of the spacecraft, also known as a spacewalk. During EVAs, astronauts are at risk of injury due to compromised human performance within the spacesuit. National Aeronautics and Space Administration (NASA) Human Research Program (HRP) is comprised of risks that could compromise the safety and efficiency of space exploration. Although risks are identified, there is missing research information and data that is necessary to further understand how to reduce risk during manned spaceflight missions. To further investigate the research gaps identified by NASA HRP, the Spacesuit Utilization of Innovative Technology Laboratory, or S.U.I.T. Lab, at Embry-Riddle Aeronautical University (ERAU) will be focusing on EVA human health and performance. With guidance from the NASA Johnson Space Center (JSC), the S.U.I.T. Lab will be performing two studies collecting data relating to spacesuit mobility, design and safety during EVAs. With the data collected, S.U.I.T. Lab will develop an operations checklist that can be used for space analogue sites for spacesuit measurements and data collection. Within this manuscript the S.U.I.T. Lab will be providing operations to fulfil space industry research needs along with furthering Science, Technology, Engineering and Math (STEM) education.

Spacesuit Range of Motion Investigations Using Video and Motion Capture Systems at Spaceflight Analogue Expeditions and within the ERAU S.U.I.T. Lab

Kobrick, R.L., Lopac, N., Schuman, J., Covello, C., French, J., Gould, A., Meyer, M., Southern, T., Lones, J. and Ehrlich, J.W., **2018**. In *48th International Conference on Environmental Systems (ICES)*

Keywords: ***HI-SEAS, MDRS***, *EVAs*, *IVAs*, *Spacesuits*, *range of motion (ROM)*, *mobility*, *biomechanics*, *intravehicular activity pressure suits*

Abstract

The Embry-Riddle Aeronautical University (ERAU) Spacesuit Utilization of Innovative Technology Laboratory (S.U.I.T. Lab) is dedicated to the pursuit of advancing human spaceflight by contributing to spacesuit and operations research with experiential programs for students. A significant portion of the S.U.I.T. Lab's portfolio is dedicated to the design and execution of spacesuit range of motion (ROM) investigations using video and motion capture systems. ROM biomechanical angles were measured using these techniques in conjunction with developing protocols for both simulated extravehicular activity suits at spaceflight analogue expeditions, and on ERAU campus with Final Frontier Design (FFD) intravehicular activity pressure suits. Designing protocols ensures effective communication for the analysis of simulated spacesuit performance to a remote crew. With communication delays to Earth, a self-sufficient spacesuit diagnosis is required to provide future astronauts with immediate action to take when dealing with a malfunctioning spacesuit. The video capture methodology is designed so that any crew would be able to conduct recordings with minimal impact to their schedule and with camera resources that are standard equipment. Spaceflight mission analogues involved in this study include: Hawai'i Space Exploration Analog and Simulation (HI-SEAS Mission V, 2017); Mars Desert Research Station (MDRS Crew 188, 2018), and AMADEE-18 in Oman (2018). Video capture can be used to

collaborate with several spacesuit manufacturers to offer a snapshot comparison between designs, validate and verify capabilities, and aid with the selection of the right suit for the right job. The analogue locations recorded unsuited and suited data, while the November FFD test focused on motion capture (with video capture taken for validation) of unsuited, suited unpressurized, and suited while pressurized to 3.5 psid conditions. Early results from the motion capture align with values estimated from video capture and future work will compare the accuracy of these techniques.

Design of T-EVA: Wearable Temperature Monitoring System for Upper Limbs during Extravehicular Activities on Mars

Palacios, P., Castillo, W., Rivera, M.V. and Cornejo, J., **2020**. In *2020 IEEE Engineering International Research Conference (EIRCON)* (pp. 1-4). IEEE.

Keywords: ***MDRS***, *EVAs*, *spacesuits*, *biomechatronic systems*, *space medicine*, *sensors*, *remote monitoring*

Abstract

When astronauts explore the surface of Mars performing extravehicular activities, they will be exposed to extreme environmental conditions that may cause thermal homeostasis imbalance, loss of sensitivity, peripheral cyanosis and heat exhaustion. For this reason, it is necessary for biomechatronic systems to be integrated into the Spacesuit, so that they allow the monitoring of vital signs as in the case of body temperature. A research study was conducted from 2019 to 2020, under the supervision and guidance of Space Medicine and Biomechatronics Research Group - TMSP, resulting in the proposed project named “T-EVA”, labeled “Medical Robot” as a Wearable Device, which consists of 5 sensors anatomically distributed in the upper plane of the human body. It sends data to a microcontroller in order to convert, process and transmit information to the “Bracelet” and the “Remote Monitoring Center” that will allow visualizing the temperature in real-time. Furthermore, T-EVA has been chosen in 2020 by The Mars Society Peru to be used and tested at The Mars Desert Research Station in Utah, the U.S., in order to be part of Team Peru VI. The conceptual design is presented, which was made using the software “Autodesk Eagle 9.6.0” for the electrical and electronic design, and “Autodesk Inventor 2020” for the mechanical design. In conclusion, favorable results were achieved; therefore, the next step of this project will be its implementation and development, which has been confirmed to be ready by 2021.

Geology

Development and Field-Testing of a Prototype Toolkit for Astronaut Planetary Exploration Activities on Moon/Mars

Brannan, J. and Bradshaw, H., **2011**. In *49th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition* (p. 834).

Keywords: ***MDRS***, *Geology*, *EVAs*, *HUD*, *field-testing*, *benchtop testing*, *on-site testing*

Abstract

A prototype of an on-site geological sample analysis toolkit was developed by students at the University of Maryland and field-tested at the Mars Desert Research Station (MDRS) in Hanksville, Utah. This portable toolkit is a collection of systems designed to aid astronauts in field geology during planetary Extra-Vehicular Activities (EVAs) on the Moon or Mars. Characteristics of the system include a self-standing, three-pronged staff with the capability to grasp rocks within and dig through various terrain settings, as well as to use a microscope and heads-up display for close examination of rock samples in the field. The heads-up display incorporates augmented reality overlays of the rock sample, enabling the subject to view the microscope-camera images inside his/her space suit. This tool has the potential to greatly advance the effectiveness of an astronaut field geologist on the Moon or Mars, enabling him/her to quickly analyze rock samples on-site. By identifying sites with more valuable science, the overall efficiency of EVA time is enhanced. The tool also reduces the astronaut's workload in the field by reducing the amount of bending and reaching required during sample collection; these are both high mobility tasks, which are difficult to perform in a pressurized suit. In order to evaluate the performance of this prototype, human factors testing was conducted at the Mars Desert Research Station, a unique Mars-analog site. Volunteer test subjects performed the following tasks with the tool: walking, digging out a rock, picking up a rock, and standing the staff upright in the ground in order to demonstrate a hands-free scenario, useful when simultaneous tasks need to be accomplished. The tasks were repeated on three different terrains: flat ground, inclined slope, and declined slope. The subjects were then asked to evaluate the ability of the tool to perform each of these tasks as well as the relative workload required to complete each task; a modified Cooper-Harper Chart was used to select the ratings. In addition to the field testing described above, benchtop testing was performed inside the MDRS Habitat in order to assess the effectiveness of the microscope and heads-up display. The comments from the test subjects were recorded during both the field-testing and bench-top testing experiments, and they serve as a very useful foundation for the development of a more refined version of the prototype geological toolkit in possible future iterations.

Geologic Field Work on Mars: Distance and Time Issues During Surface Exploration

Kereszturi, A., **2011**. *Acta Astronautica*, *68*(11-12), pp.1686-1701.

Keywords: ***MDRS***, *Geology*, *EVAs*, *Field work*, *Exploration*, *Proposed running head*, *Geologic field work on Mars*, *terrain types*, *in-situ exploration*, *rovers*

Abstract

Based on field experience at Analogue stations MDRS and FMARS and additional theoretical computations, motorized field work traverses were planned for various surface feature types on Mars, with emphasis on their horizontal dimension, maximal slope angle and cumulative vertical surface undulation or roughness. The aim was to explore the possibilities and characteristics of field work for

different terrain types. Those terrain types are reviewed in the present study that have already been analyzed based on remote sensing data, and that are described in the scientific literature.
Dunes, gullies, slope streaks, cross sections of valley networks and of lava channels might be analyzed during only one extra vehicular activity (EVA, e.g., pedestrian and vehicular field work) with the objective of a first in-situ exploration along an optimized traverse, in order to provide the most valuable scientific information on their general characteristics and origin. Smaller tectonic faults, lava flows, lobate debris aprons and outcrops of polar layered deposits can be analyzed only by several EVAs together. Analysis of large landslides, calderas and interior layered deposits produce even more difficulties on Mars, and require specialized technology. In cases where several EVAs are necessary for detailed analysis along the best traverse, mobile pressurized vehicles (with pressurized cabin for astronauts without spacesuits) or other methods would be necessary.
Many of the geologic structures that have been analyzed only with remotely sensed data could not be surveyed during one field campaign, and in some cases because of high slope angle and large cumulative topographic undulation, their in-situ exploration could not be accomplished with the technological capabilities available, and in-situ analysis requires more advanced technology than long distance rovers can provide now. Hence, the prior location of important sites and the usage of robotic help will be of high importance.

Conducting Rock Mass Rating for Tunnel Construction on Mars

Beemer, H.D. and Worrells, D.S., **2017**. *Acta Astronautica*, *139*, pp.176-180.

Keywords: ***MDRS***, *Geology*, *radiation*, *Rock Mass Rating*, *EVAs*, *tunnel construction*, *applied geology*,

Abstract

Mars analogue missions provide researchers, scientists, and engineers the opportunity to establish protocols prior to sending human explorers to another planet. This paper investigated the complexity of a team of simulation astronauts conducting a Rock Mass Rating task during Analogue Mars missions. This study was conducted at the Mars Desert Research Station in Hanksville, UT, during field season 2015/2016 and with crews 167,168, and 169. During the experiment, three-person teams completed a Rock Mass Rating task during a three hour Extra Vehicular Activity on day six of their two-week simulation mission. This geological test is used during design and construction of excavations in rock on Earth. On Mars, this test could be conducted by astronauts to determine suitable rock layers for tunnel construction which would provide explorers a permanent habitat and radiation shielding while living for long periods of time on the surface. The Rock Mass Rating system derives quantitative data for engineering designs that can easily be communicated between engineers and geologists. Conclusions from this research demonstrated that it is feasible for astronauts to conduct the Rock Mass Rating task in a Mars simulated environment. However, it was also concluded that Rock Mass Rating task orientation and training will be required to ensure that accurate results are obtained.

The Drinkable Rock: Improvised Methods to Extract H20 from Minerals for Resource Depleted Emergencies on Future Mars Missions

Whitfield, S., MacQuarrie, A., Wheeler, A. and Wilson, L., **2020**. *Safety in Extreme Environments*, *2*, pp.231-238.

Keywords: ***MDRS***, *geology*, *ISRU*, *water*, *disaggregation*, *distillation*, *improvised tools*

Abstract

Once inhabited, medical emergencies will occur on Mars where human survival will depend ultimately on the availability of water. This research aimed to explore the hypothesis that medical crews working

in an austere and extreme environments could extract mineral bound water through improvised methods using only items accessible to the crew from the habitat. During a Mars simulation crew members collected surface gypsum, a hydrate mineral, and attempted three improvised methods to extract the mineral bound water through a heating, disaggregation and distillation process. The methods produced differing results however the total extracted mass of water as a percentage of the total sample mass varied from 0.39% to 7.4%. By utilizing items found in the habitat only; the crew were able, through improvised strategies, to achieve a proof of concept by extracting water from minerals during the simulated mission.

Analog Field Sites on Hawai'i Island

Romo, R., Andersen, C., Edison, K. and Musilova, M., **2021**. In *Earth and Space 2021* (pp. 577-589).

Keywords: ***HI-SEAS***, *Geology*, *ISRU*, *chemical composition*, *regolith*, *Mars analogue environment*

Abstract

NASA's Artemis program has created new interest in analog test sites where technologies being developed for the lunar surface can be tested during their developmental phases. Analog sites provide excellent, realistic, suitable, and economical accessible environments to carry out scientific research relevant to the exploration of the Moon and Mars. In addition, these sites are used in support of space exploration to evaluate surface mobility systems and auxiliary components in a realistic environment and terrain. The Island of Hawai'i has a long history of analog testing dating back to the Apollo days. Formed by five different volcanoes, the island offers a wide range of high fidelity analog test sites. Chemical composition of the basalt from the island has also shown close similarities with lunar and Mars regolith, making it a good simulant for some ISRU applications. The Pacific International Space Center for Exploration Systems (PISCES) has been offering analog site testing logistic support since 2008. In this paper, three different analog sites will be described as well as the support capabilities that PISCES can offer during test missions.

Geological Tasks During HI-SEAS Planetary Analog Mission Simulations, Mauna Loa, Hawai'i

Shiro, B.R., Rowland, S.K., Hurtado, J.M., Caldwell, B.J., Bleacher, J.E., Fagents, S.A., Roma, P.G., Bedwell-Torres, W.L. and Binsted, K., **2022**. *Planetary and Space Science*, *212*, p.105409.

Keywords: ***HI-SEAS***, *Geology*, *EVAs*, *GPS*, *mapping*, *crew training*, *exploration*, *volcanology*

Abstract

The Hawai'i Space Exploration Analog and Simulation (HI-SEAS) project is a NASA-funded research program operating long-duration planetary analog surface mission simulations on Mauna Loa volcano, Hawai'i. During missions lasting from 4 to 12 months, crews of six analog astronaut participants live and work in an isolated habitat, communicating with a remote mission support team via a 20-min time delay. The main purpose of HI-SEAS is to study team effectiveness and adaptation over time in isolated, confined, and high autonomy mission scenarios. Among other duties, Crewmembers are tasked with routinely conducting geological fieldwork requiring extravehicular activity (EVA) in the environment surrounding the habitat. They must determine how they will accomplish these tasks, conduct the tasks themselves, and report results by a due date set by the remote science team. Here we describe the design, task parameters, and performance outcomes of HI-SEAS geology EVA tasks from four 6-person missions. We describe the assigned tasks, how the crews carried out their assignments, and the results of their work in terms of six performance metrics for each task: 1) number of days required for

completion; 2) number of crewmembers participating; 3) number of EVAs required; 4) total EVA time required; 5) difference between required and planned EVA times; and 6) performance score evaluating how well crew met the task objective. We find weak evidence of a decrease in geology task performance during the third quarter of missions M2-M4. This dataset provides insights into varying crew performance over time for different mission durations.

A Sequential Approach for On-board Rock Detection from Lunar Images

Bosowski, P., Sadel, J., Cwiek, M., Strzalka, T., Wiejak, M., Benecki, P. and Kawulok, M., **2023**. In *IGARSS 2023-2023 IEEE International Geoscience and Remote Sensing Symposium* (pp. 4195-4197). IEEE.

Keywords: ***LunAres***, *Geology*, *rovers*, *software*, *U-Net architecture*, *contrast-limited adaptive histogram equalization (CLAHE) algorithm*, *YOLO model*, *rock segmentation*, *deep learning modules*

Abstract

Rock segmentation in lunar images is a crucial computer vision task for visual navigation of planetary rovers. Even though numerous approaches have been already proposed to address this task, many solutions are underpinned with computationally-intensive deep learning models, which makes them unsuitable for on-board processing. In the study reported here, we address this important problem and we propose a sequential pipeline, which combines a U-Net-based network for rock segmentation with a YOLO model for final object detection. We demonstrate that putting two lightweight models together improves the detection performance, making it close to that obtained with full-sized architectures. Even though this is an initial study, the obtained results indicate that this direction is promising and it is worthy of further investigation.

Life Support Systems - Dust

Mars Habitat Dust Contamination from Simulated Extra-Vehicular Surface Activity

Bos, B.J. and Scott, D., **2004**. From *The Mars Society*

Keywords: ***MDRS***, *LSS*, *dust*, *soil*, *EVAs*, *contamination*, *Mars hazards*, *regolith*, *terrain*

Abstract

After the high radiation environment and the low gravity field on Mars, dust is arguably the next biggest hazard facing a manned mission to Mars. The seriousness of the threat depends on the specific characteristics of Martian dust and soil, which we are still trying to understand through robotic missions. At its most benign, Martian dust could cause premature failures in mechanical, electrical and thermal systems. And at its most hazardous, it could cause debilitating illness and jeopardize the health of the crew.

From April 26 to May 10, 2003, a 7 person, international crew manned the Mars Society's Mars Desert Research Station (MDRS) located near Hanksville, Utah. During that two-week period, the crew lived and explored the surrounding desert terrain under the constraints of NASA's Mars surface reference mission. One of the primary research objectives of the simulation was to study the amount of dust brought into the MDRS from the surrounding Mars analogue terrain during simulated extra-vehicular activity (EVA). This work characterized the soil and dust contamination brought into the Habitat through 12 out of the 14 simulated EVA's. The amount of dust, in terms of mass, and the sizes and shapes of the contaminating dust particles were measured. EVA characteristics such as type (pedestrian, all-terrain vehicle or pressurized rover), distance traveled and the work engaged were recorded to study their affect and relationship to dust contamination. We found that more than 50 g of dust and soil were transported into the MDRS during the 12 EVAs that were measured. And the amount of contamination from EVA activity was most strongly dependent on the type of terrain over which the EVA was conducted.

Habitat Dust Contamination at a Mars Analog

Bos, B.J., Scott, D.J. and Metzger, S.M., **2011**. *Geological Society of America Special Papers: Analogs for Planetary Exploration*, Editors: W. Brent Garry, Jacob E. Bleacher. 483, pp.137-155.

Keywords: ***MDRS***, *LSS*, *dust*, *EVAs*, *contamination*, *dust dynamics*, *rovers*, *terrain*, *airlock*

Abstract

After the high-radiation environment and the low gravity field on Mars, dust is arguably the next biggest environmental hazard facing a manned mission to Mars. The seriousness of this threat is still being studied with robotic missions. At its most benign, Martian dust the work undertaken were recorded to study their effects on dust contamination. We found that more than 50 g of dust and soil were transported into the Mars Desert Research Station (MDRS) during the 12 EVAs (extravehicular activities) that were measured. The largest amount of contamination from EVA activity was due to open-cockpit vehicle travel and depended strongly on the terrain over which the EVA was conducted. Based on first-order dust dynamics modeling, similar behaviors are expected on Mars.

Preparing for Planetary Surface Exploration by Measuring Habitat Dust Intrusion with Filter Tests During an Analogue Mars Mission

Kobrick, R.L. and Agui, J.H., **2019**. *Acta Astronautica*, *160*, pp.297-309.

Keywords: ***MDRS***, *LSS*, *dust*, *contamination*, *optical particle counter*, *dust related damage*, *planetary surface*, *filter*, *operations*, *airlock*, *EVAs*, *dust load*

Abstract

As humans venture deeper into space more issues related to operations will become apparent. While the perils of dust particles may not be widely recognized, it is one of the major issues astronauts will face on the surface of the Moon and Mars. Dust particles present a problem for both astronaut health and equipment as revealed during the Apollo era lunar surface missions. Dust particles cling to spacesuits and field gear, which upon ingress would begin circulating throughout the spacecraft or habitat. An astronaut's health is compromised by the dust particle's potential to embed in the lungs and cause respiratory illnesses. The extreme abrasiveness and granularity of the particles make it near impossible to completely shield a spacecraft or habitat from dust related damage. NASA's Glenn Research Center (GRC) collaborated with Crew 188 at the Mars Desert Research Station (MDRS) in Utah to measure how much dust entered the habitat during a series of extravehicular activities (EVAs), or surface excursions. A NASA GRC developed multistage filter system, coined the Scroll Filter System, was tested, for its effectiveness in removing dust that entered the airlock and habitat after the EVAs. An optical particle counter measured the ambient airlock particulates five times including: before the start of operations; after the crew left for EVA; in the middle of the EVA with the settled air; before the crew entered the airlock after EVA; and finally, after the crew simulated re-pressurization and suit brushing off in the airlock. Data was also collected in several of the working environment locations around MDRS and outside the habitat in the wind. Data collected from this research will help establish filter equipment for life support systems and prescribed operations for astronaut transition from a planetary surface into a desired clean habitat. Measurements may aid in updating a baseline expected dust load for a surface habitat and further facilitate the mitigation of astronaut's exposure to dust particles on the surface of celestial bodies.

Life Support Systems - Food

First Observations Regarding the Psychological Impact of Growing Vegetables During a Manned Mars Mission Simulation at the Mars Desert Research Station

Pletser, V. and Lasseur, C., **2003**. In *54th International Astronautical Congress of the International Astronautical Federation, the International Academy of Astronautics, and the International Institute of Space Law* (pp. IAA-10).

Keywords: ***MDRS***, *LSS, food, greenhouses, vegetables, germination, pyschology*

Abstract

The amount of food to bring and eventually to produce on Mars during a manned mission and the psychological aspect for a human crew to be cut from an earth-like environment and to live and work in an isolated environment are still debated. Design considerations of a greenhouse as part of a Martian human settlement include, beside growing vegetables for consumption, the possibility for astronauts to attend plants and relax in a garden-like area, possibly reminiscent of an earthly environment. During international simulation campaigns of manned Martian missions organized by The Mars Society, several human crews lived and worked in confined isolation. International crews of mixed gender and professional qualifications conducted various scientific and operational tasks as Martian crews would. Operations were conducted as they would be during a Martian mission, including delays in radio communications and Extra-Vehicular Activities (EVA) with specially designed unpressurized suits. During a two week simulation of a manned Mars mission at the Mars Desert Research Station (MDRS), four different sort of vegetables have been grown for 12 days in the manned Habitat and in a detached experimental greenhouse accessible during simulated EVA's. The six crew members were asked to participate in the observation and reporting of the germination and growth process. At the end of the simulation, vegetables were harvested and consumed by the crew. The crew members were asked to comment on the taste and their feelings about eating this home grown production.

This paper summarizes first the activities of seed planting, growing and harvesting conducted during the simulation; second, the observations on psychological impact on the crew of growing plants during isolation in the manned Habitat and in the greenhouse; and third, the crew assessment on their appreciation of the vegetable consumption on the last evening. Indications and suggestions for design of plant growing facilities in future Martian Habitat are given in conclusion.

Demonstration Test of Electrical Lighting Systems for Plant Growth in HI-SEAS Analog Mars Habitat

Poulet, L., Massa, G.D., Wheeler, R., Gill, T., Morrow, R., Steele, C., Swarmer, T., Binsted, K. and Hunter, J., **2014**. In the *65th International Astronautical Congress (IAC)*

Keywords: ***HI-SEAS***, *LSS, food production, greenhouse systems, lighting, biomass, lettuce, radish, wavelengths, LEDs, heliospectra lamps, psychology*

Abstract

Greenhouse modules and regenerative life-support systems are critical for long-duration space missions and future settlements on the Moon and Mars; understanding their mechanisms and issues on Earth in remote areas is a first step towards their space adaptation. To follow up with studies

performed in NASA's Deep Space Habitat and deployed at NASA Desert Research and Technology Studies test site in 2010 and 2011, and at NASA Johnson Space Center in 2012, three sole-source LED lighting systems – commercial-off-the-shelf "UFO" red and blue LED grow lights, AIBC's super-slim whiteEx70Dim panels, and Heliospectra multispectral LX60 lamp – were tested during the four-month HI-SEAS (Hawaii Space Exploration and Analog Simulation) analog mission. The primary objective of this study was to assess the effects of different wavelengths on lettuce and radish growth in a semi-controlled environment. Crew time required to take care of plants was also assessed. A Biomass Production System for Education (BPSe) unit developed by ORBITEC and modelled after their Deployable Vegetable Production System was placed inside the habitat and available for crew interaction and recreational purposes. Preliminary results regarding psychological benefits of plants in remote areas during long-term isolation are presented.

Greenhouse Automation, Illumination and Expansion Study for Mars Desert Research Station

Poulet, L. and Doule, O., **2014**. In *the 65th International Astronautical Congress (IAC)*

Keywords: **MDRS**, LSS, food production, greenhouse systems, vegetables, flowers, illumination, GreenHab, low humidity

Abstract

A partially or fully autonomous food production facility is one of the most important elements in any extraterrestrial settlement. The GreenHab, the greenhouse of the Mars Desert Research Station (MDRS), provides an excellent opportunity for an expansion study, considering it both as an experimental facility for crop growth but also as a food provider for the crew. The current GreenHab is a basic horizontal cylindrical structure divided into two parts. The larger part is used for vegetables growth over the season, which are harvested and consumed by the latest crews in rotation at the station. It also provides the opportunity to perform experiments within the greenhouse facility. The second part is dedicated to the crew well-being in form of a Zen garden with flowers. The MDRS GreenHab is an independent module linked to the main habitat through a corridor. Full integration of the greenhouse module into the habitat would be preferable since on top of participating to food production it could directly support air revitalization and water recycling, which are life-critical processes related to all human operations in the base. The MDRS internal environment suffers from extremely low humidity (e.g., 18- 22% during February) due to its location in the high desert of Utah and also due to its heat and ventilation air conditioning system design that is not integrated with the other base subsystems. An integrated greenhouse could improve the atmosphere quality and decrease crew health risks as well as increase their comfort and work efficiency. Greenhouse systems are not hazardous (in opposition to some power systems requiring specific distance from the base due to possible life endangering failures) and thus do not require protective zoning apart from the habitation unit, which makes their integration into the habitat a plausible scenario. This paper presents number of approaches and options for the GreenHab automation, illumination and capacity expansion based on various research, production and base operations interests. Currently the GreenHab requires much crew time for maintenance and daily operations, which could be reduced by at least a third using automation techniques. The use of supplemental lighting would also greatly improve light conditions inside the GreenHab, therefore enhancing crop growth and yield of the greenhouse. There are numerous options for the GreenHab expansion such as: modular, dome radial,

detached, attached from pre-fabricated components, self-deployable or built of in-situ resources depending on the level of habitat and greenhouse simulations and structures fidelity.

Plant Growth Optimization by Vegetable Production System in HI-SEAS Analog Habitat

Ehrlich, J.W., Massa, G., Wheeler, R., Gill, T.R., Quincy, C., Roberson, L., Binsted, K. and Morrow, R., **2017**. In *AIAA Space and astronautics forum and exposition* (p. 5143).

Keywords: ***HI-SEAS***, *LSS*, *food production systems*, *vegetables*, *LEDs*, *lighting*, *rooting pillows*, *plant growth substrate*, *capillary watering*, *thermal control*, *humidity control*, *Veggie*

Abstract

The Vegetable Production System (Veggie) is a scientific payload designed to support plant growth for food production under microgravity conditions. The configuration of Veggie consists of an LED lighting system with modular rooting “pillows” designed to contain substrate media and time-release fertilizer. The pillows were designed to be watered passively using capillary principles but have typically been watered manually by the astronauts in Low Earth Orbit (LEO). The design of Veggie allows cabin air to be drawn through the plant enclosure for thermal and humidity control and for supplying CO2 to the plants. Since its delivery to the International Space Station (ISS) in 2014, Veggie has undergone several experimental trials by various crews. Ground unit testing of Veggie was conducted during an 8-month Mars analog study in a semi-contained environment of a simulated habitat located at approximately 8,200 feet (2,500 m) elevation on the Mauna Loa volcano on the Island of Hawai’i. The Hawai’i Space Exploration Analog and Simulation (HI-SEAS) offered conditions (habitat, mission, communications, etc.) intended to simulate a planetary exploration mission. This paper provides data and analyses to show the prospect for optimized use of the current Veggie design for human habitats. Lessons learned during the study may provide opportunities for updating the system design and operational parameters for current Veggie experiments being conducted onboard the ISS and for payloads on future deep space missions.

Hydrogels Improve Plant Growth in Mars Analog Conditions

Peyrusson, F., **2021**. *Frontiers in Astronomy and Space Sciences*, *8*, p.729278.

Keywords: ***MDRS***, *food production*, *hydrogel supplementation*, *ISRU*, *Martian soil*, *Martian regolith*, *plant cultivation*, *spearmint*, *radish*, *water retention*, *irrigation*

Abstract

Sustainable human settlement on Mars will require in situ resource utilization (ISRU), the collection and utilization of Mars-based resources, including notably water and a substrate for food production. Plants will be fundamental components of future human missions to Mars, and the question of whether Mars soils can support plant growth is still open. Moreover, plant cultivation may suffer from the lack of in situ liquid water, which might constitute one of the biggest challenges for ISRU-based food production on Mars. Enhancing the crop yield with less water input and improving water utilization by plants are thus chief concern for sustainable ISRU food production. Hydrogels are polymers able to absorb large quantity of water and to increase soil water retention, plant establishment and growth. This work reports on the short-term assessment of plant growth in Mars soil analogs supplemented with hydrogels. Soil analogs consisted of sand and clay-rich material, with low organic matter content and alkaline pH. Soils were supplemented with 10% (w/w) potting medium and were sampled in Utah desert, in the vicinity of the Mars Desert Research Station, surrounded by soils sharing similarities in mineralogical and chemical composition to Martian soils. Height and dry

biomass of spearmint (*Mentha spicata*) were compared under various irrigation frequencies, and seed germination of radish (*Raphanus sativus*) were monitored. Under limited irrigation, results indicate that the soil analogs were less capable of supporting plant growth as a comparison to potting medium. The effects of hydrogel supplementation were significant under limited irrigation and led to spearmint heights increased by 3 and 6% in clay- and sand-containing soils, respectively. Similarly, hydrogel supplementation resulted in spearmint mass increased by 110% in clay-containing soils and 78% in sand-containing soils. Additionally, while radish seeds failed to germinate in soil analogs, hydrogel supplementation allows for the germination of 27% of seeds, indicating that hydrogels might help loosening dense media with low water retention. Collectively, the results suggest that supplementation with hydrogel and plant growth substrate could help plants cope with limited irrigation and poor alkaline Mars soil analogs, and are discussed in the context of strategies for ISRU-based off-world colonization.

Crew Time in a Space Greenhouse Using Data from Analog Missions and Veggie

Poulet, L., Zeidler, C., Bunchek, J., Zabel, P., Vrakking, V., Schubert, D., Massa, G. and Wheeler, R., **2021**. *Life Sciences in Space Research*, *31*, pp.101-112.

Keywords: ***HI-SEAS***, ***MDRS***, *LSS*, *food production*, *Veggie*, *crew time*, *reporting*, *time management*

Abstract

Crew time requirements for human space exploration missions is as critical as mass, energy, and volume requirements. However, it has only been sporadically recorded in past analog and space missions for plant cultivation. In this retrospective study on crew time data collected in various analog facilities and on the Veggie hardware on ISS, we propose a methodology for efficient categorizing and reporting of crew time in space plant growth systems. Crew time is difficult to capture in operational environments, and this study intends to harmonize these efforts among different locations. This article also provides a current database for required crew time in several plant growth hardware and facilities, on the ISS, and on Earth. These data could serve mission planners as a baseline to establish standardized activities and extrapolate crew time needed to operate future plant growth units. Finally, we discuss how crew time needed for plant cultivation will change in future exploration missions, based on choices made for plant species, watering systems, level of automation, and use of virtual assistants, among others. Crew time will need to be accounted for as a decisive factor to design future space greenhouse modules.

Life Support Systems - Recycling and Waste

Human Factor Investigation of Waste Processing System During the HI-SEAS 4-Month Mars Analog Mission in Support of NASA's Logistic Reduction and Repurposing Project: Trash to Gas

Caraccio, A., Hintze, P.E. and Miles, J.D., **2014**, In *65th International Astronautical Congress* (No. KSC-E-DAA-TN17851).

Keywords: ***HI-SEAS***, *LSS, experimental waste processing , recycling, reuse, gas concentrations, engineering, human factors, crew interface, utility usage, waste storage, waste generation*

Abstract

NASA's Logistics Reduction and Repurposing (LRR) project is a collaborative effort in which NASA is tasked with reducing total logistical mass through reduction, reuse and recycling of various wastes and components of long duration space missions and habitats. Trash to Gas (TtG) is a sub task to LRR with efforts focused on development of a technology that converts wastes generated during long duration space missions into high-value products such as methane, water for life support, raw material production feedstocks, and other energy sources. The reuse of discarded materials is a critical component to reducing overall mission mass. The 120 day Hawaii Space Exploration and Analog Simulation provides a unique opportunity to answer questions regarding crew interface and system analysis for designing and developing future flight-like versions of a TtG system. This paper will discuss the human factors that would affect the design of a TtG or other waste processing systems. An overview of the habitat, utility usage, and waste storage and generation is given. Crew time spent preparing trash for TtG processing was recorded. Gas concentrations were measured near the waste storage locations and at other locations in the habitat. In parallel with the analog mission, experimental processing of waste materials in a TtG reactor was performed in order to evaluate performance with realistic waste materials.

Investigation Of Bio-Regenerative Life Support and Trash-To-Gas Experiment on a 4-Month Mars Simulation Mission

Caraccio, A., Poulet, L., Hintze, P. and Miles, J.D., **2014**. In *65th International Astronautical Congress* (IAC)

Keywords: ***HI-SEAS***, *LSS, ECLSS, BLSS, bio-regenerative life support systems, environmental control, semi-closed loop system, waste, recycling, gas, plant material recycling, power and water consumption, energy conversion techniques*

Abstract

Future crewed missions to other planets or deep space locations will require regenerative Life Support Systems (LSS) as well as recycling processes for mission waste. Constant resupply of many commodity materials will not be a sustainable option for deep space missions, nor will stowing trash on board a vehicle or at a lunar or Martian outpost. The habitable volume will decline as the volume of waste increases. A complete regenerative environmentally controlled life support system (ECLSS) on an extra-terrestrial outpost will likely include physicochemical and biological technologies, such as bioreactors and greenhouse modules. Physico-chemical LSS do not enable food production and bio-

regenerative LSS are not stable enough to be used alone in space. Mission waste that cannot be recycled into the bio-regenerative ECLSS can include excess food, food packaging, clothing, tape, urine and fecal waste. This waste will be sent to a system for converting the trash into high value products. Two crew members on a 120 day Mars analog simulation, in collaboration with Kennedy Space Center's (KSC) Trash to Gas (TtG) project investigated a semi-closed loop system that treated non-edible biomass and other logistical waste for volume reduction and conversion into useful commodities. The purpose of this study is to show how plant growth affects the amount of resources required by the habitat and how spent plant material can be recycled. Real-time data was sent to the reactor at KSC in Florida for replicating the analog mission waste for laboratory operation. This paper discusses the 120 day mission plant growth activity, logistical and plant waste management, power and water consumption effects of the plant and logistical waste, and potential energy conversion techniques using KSC's TtG technology.

Forward Osmosis Flow Rate Differential Using Different Osmotic Agents

Trzinski, J.M., **2019**. *Beyond: Undergraduate Research Journal*, *3*(1), p.2.

Keywords: ***LunAres***, *LSS*, *water filter*, *filtration*, *osmosis*, *flow rate*, *hydrodynamics*, *concentration gradients*, *power saving*

Abstract

Life support is one of the most vital systems flown on manned spaceflight missions. The systems currently used are large, heavy, inefficient, and power consuming in an environment that requires nearly perfect conditions to function. Forward Osmosis (FO) is a form of filtration that uses the natural properties of water and concentration gradients to filter water without the need for any electricity. An experiment was conducted during the Embry Riddle Summer 2018 study abroad to the LUNARES research station in Piła, Poland. This experiment explored how the flow rate of water through a FO filtration system could be affected by the use of different osmotic feed solutions. The results show the differences in average flow rate and flow rate consistency. The findings could be used to improve the efficiency of the FO system which in turn could be used in future life support systems in long-term manned space exploration missions.

Design of Hygiene Module Using Closed Grey Water Cycle for Lunares Research Station–Main Assumptions and Applications

Mintus AS, Orzechowski L., Ćwilichowska N., Jurga J., **2020**. In *71st International Astronautical Congress (IAC)*

Keywords: ***LunAres***, *LSS*, *grey water*, *recycling*, *self-sufficiency*, *architecture design*, *functional study*, *flow meters*, *water usage*, *hygiene module*, *psychology*, *hydroponics*, *aeroponics*, *aquaponics*

Abstract

LunAres Research Station is an analog habitat located in Pila, Poland. The facility focuses on conducting medical and psychological studies on isolated teams up to 6 analog astronauts. The infrastructure of the habitat consists of isolated 250 square meter Extra-Vehicular Activity Area and 176 square meter habitat with eight modules including different functions. In recent years during constant work on the improvement of the LunAres facility the decision was made to put emphasis on sustainable development. As a result a new hygiene module was designed and built. New installation allows for collecting grey-water as well as its treatment and re-use according to ongoing research. The module also includes a dry toilet that produces compost and allows easy biological sample collection. All equipment and systems are located in a 30m^2 mobile sea container equipped with basic hygiene

installations and designed with reduced mobility users in mind. The space allows for performing various experiments, adding spacious equipment inside and developing the technologies focusing on off-grid and self-sufficient building. All installations in the container are accompanied by separated flow meters for detailed monitoring of water usage. The paper includes planned testing of facilities during new analog campaigns in LunAres, which will take place in November 2020. Grey water module will be tested for water consumption levels as well as the psychological and physical impact on the crew members and potential impact of treated grey water on plants in hydro, aero and aquaponic systems.

Microbiology

Periodontal Status, Salivary Immunoglobulin, and Microbial Counts After Short Exposure to an Isolated Environment

Rai, B. and Kaur, J., **2013**. *Journal of Oral Science*, *55*(2), pp.139-143.

Keywords: ***MDRS***, *microbiology*, *oral microbiology*, *salivary microorganisms*, *immunoglobulins*, *α-amylase*, *salivary flow rate*, *plaque*, *clinical periodontal parameters*, *Salivary IgG levels*, *Streptococcus mutans activity*, *stress*

Abstract

Salivary flow rate, immunoglobulin, and periodontal status were affected during a simulated Skylab mission. The effect is more prominent after long-duration space flights and can persist for several weeks after landing. The objective of this study was to determine the effect of a simulated Mars environment on periodontal status and levels of salivary microorganisms and immunoglobulins in the human oral cavity. Twelve healthy male volunteers were studied before, at 1 and 2 weeks, and after completion of a mission in an isolated, confined simulated Mars environment at the Mars Desert Research Station, USA. We conducted a current stress test, measured salivary immunoglobulin, cortisol, α-amylase, salivary flow rate, and levels of plaque and salivary microbes, and assessed clinical periodontal parameters (probing depth, bleeding on probing, and clinical loss of attachment). Salivary IgG levels and *Streptococcus* mutans activity were significantly higher at 1 week. Values for clinical periodontal parameters (probing depth, bleeding on probing, and clinical loss of attachment) significantly differed at 1 week. Stress might be caused by the difficulty of the mission rather than the isolated environment, as mission duration was quite short. Periodontal condition might worsen due to poor oral hygiene during the mission. The present findings show that all periodontal conditions and levels of oral bacteria and stress after completion of the simulated Mars mission differed from those at baseline. To verify the relationship between stress status and periodontal health in simulated Mars missions, future studies using larger patient samples and longer follow-up will be required.

Hydrogel Bacterial Cellulose: A Path to Improved Materials for New Eco-Friendly Textiles

Kamiński, K., Jarosz, M., Grudzień, J., Pawlik, J., Zastawnik, F., Pandyra, P. and Kołodziejczyk, A.M., **2020**. *Cellulose*, *27*, pp.5353-5365.

Keywords: ***LunAres***, *Microbiology*, *applied microbiology*, *textiles*, *cellulose*, *yeast*, *bacteria*, *wettability*, *mechanical properties*, *flame resistance*, *energy consumption*, *spectroscopy*, *synthesized fabrics*, *green chemistry*

Abstract

In this paper, we present a novel, ecologically friendly technology for the synthesis and modification of kombucha-derived bacterial cellulose in order to produce textiles of desired physicochemical and mechanical properties. The procedure of manufacturing cellulose in the form of a stable hydrogel bacterial cellulose (HGBC) ensures the desired properties for the application of such a material, e.g., in the textile industry. Bacterial cellulose was obtained from a yeast/bacteria kombucha culture (a symbiotic consortium also known as “tea fungus” or SCOBY) that is easy and cheap to breed. The process of bacterial cellulose manufacturing and modification was optimized in order to obtain a maximum recovery of raw materials, minimal energy consumption and ensure the use of only natural

and renewable resources. The obtained materials were characterized in terms of their wettability, mechanical properties, and flame resistance. Moreover, the morphology and composition of the materials were determined by using scanning electron microscopy and infrared spectroscopy, respectively. Additionally, it was proven that the HGBC materials might be used to manufacture various articles of clothing using commonly available sewing techniques, which are not adequate for non-modified cellulose-based materials. Finally, the synthesized fabrics were used as wristbands and parts of T-shirts and tested on volunteers to determine a skin-to-skin contact behaviour of the prepared fabrics. The reported results allow for confirming that the HGBC fabric may be used as a new textile and the proposed synthesis method is in accordance with the “green chemistry.”

Microbiome Dynamics During the HI-SEAS IV Mission, and Implications for Future Crewed Missions Beyond Earth

Mahnert, A., Verseux, C., Schwendner, P., Koskinen, K., Kumpitsch, C., Blohs, M., Wink, L., Brunner, D., Goessler, T., Billi, D. and Moissl-Eichinger, C., **2021**. *Microbiome*, *9*(1), pp.1-21.

Keywords: ***HI-SEAS***, *Microbiology*, *longitudinal 16S rRNA gene profiles*, *crew sampling*, *surface sampling*, *microbial diversity*, *microbial transfer*, *PCR*, *bioinformatics*

Abstract

BACKGROUND: Human health is closely interconnected with its microbiome. Resilient microbiomes in, on, and around the human body will be key for safe and successful long-term space travel. However, longitudinal dynamics of microbiomes inside confined built environments are still poorly understood. Herein, we used the Hawaii Space Exploration Analog and Simulation IV (HI-SEAS IV) mission, a 1 year-long isolation study, to investigate microbial transfer between crew and habitat, in order to understand adverse developments which may occur in a future outpost on the Moon or Mars.

RESULTS: Longitudinal 16S rRNA gene profiles, as well as quantitative observations, revealed significant differences in microbial diversity, abundance, and composition between samples of the built environment and its crew. The microbiome composition and diversity associated with abiotic surfaces was found to be rather stable, whereas the microbial skin profiles of individual crew members were highly dynamic, resulting in an increased microbiome diversity at the end of the isolation period. The skin microbiome dynamics were especially pronounced by a regular transfer of the indicator species *Methanobrevibacter* between crew members within the first 200 days. Quantitative information was used to track the propagation of antimicrobial resistance in the habitat. Together with functional and phenotypic predictions, quantitative and qualitative data supported the observation of a delayed longitudinal microbial homogenization between crew and habitat surfaces which was mainly caused by a malfunctioning sanitary facility.

CONCLUSIONS: This study highlights main routes of microbial transfer, interaction of the crew, and origins of microbial dynamics in an isolated environment. We identify key targets of microbial monitoring, and emphasize the need for defined baselines of microbiome diversity and abundance on surfaces and crew skin. Targeted manipulation to counteract adverse developments of the microbiome could be a highly important strategy to ensure safety during future space endeavors.

Examination into the HI-SEAS IV Built Environment Reveals Differences in the Microbial Diversity and Composition of Plastic and Wood Surfaces

Li, D., Ching, K. and Hunt, W., **2021**. *Undergraduate Journal of Experimental Microbiology and Immunology*, *26*.

Keywords: ***HI-SEAS***, *Microbiology*, *abiotic surfaces*, *alpha and beta diversity*, *microbial communities*, *microbial dynamics*, *long-term habitation*

Abstract

The conditions within a confined built environment designed for long-term habitation during space travel can influence the microbiomes of the abiotic surfaces, emphasizing the necessity of regular microbial screens. The recent Hawaii Space Exploration Analog and Simulation (HI-SEAS) IV study examined the microbiome of a confined environment built to mimic a habitat on Mars. Temporal variations in microbial diversity were identified within the HI-SEAS built environment, but the factors associated with the observed microbial dynamics had yet to be explored. Here, we identified these factors by investigating the potential effect of resupply events and surface material on microbial diversity and composition. We found that resupply events had no significant effect on the alpha or beta diversity of the microbiome within the HI-SEAS built environment, but that plastic and wood surfaces exhibited significant differences in alpha and beta diversity. Together, our study provides insights into the considerations for monitoring microbial communities within a confined habitat designed for space exploration.

Examination into the HI-SEAS IV Crew Member Microbiome Reveals Potential Role of Preferred Interactions on Skin Microbial Community Structure

Frese, K., Naraina, B., Pornsinsiriruk, V. and Shad, A., **2022**. *Undergraduate Journal of Experimental Microbiology and Immunology*, *8*.

Keywords: ***HI-SEAS***, *skin microbiomes*, *alpha and beta diversity*, *longitudinal volatility analysis*, *taxonomic classifications*, *PCoA analysis*, *differential abundance analysis*, *skin health*

Abstract

Astronauts experiencing prolonged space travel report increased skin hypersensitivity and delayed wound healing as a result of changes to the skin microbiome during space travel. In this study, we explored the effects of close social relationships within isolated built environments on the human skin microbiome. We analyzed the effect of crew interactions on the microbiome dynamics of six astronauts using a dataset from a year long Earth-bound Mars simulation called the Hawaii Space Exploration Analog and Simulation IV (HI-SEAS IV) mission. Microbial profiles were processed by Mahnert *et al.* based on amplicons targeting the V4 region of the 16S rRNA gene. We performed alpha and beta diversity longitudinal volatility analysis, taxonomic classifications, PCoA analysis, differential abundance analysis, and designed Venn diagrams to determine changes in microbiome dynamics. Within the dataset, we found that crew member pairs appeared to trend towards similar skin microbiomes, and microbiomes within pairs were found to be significantly more similar than between pairs. Furthermore, we found that the taxonomic composition of crew member skin microbiomes changed significantly between final and initial time points of the year-long mission. Our results suggest a potential for close physical interactions to modulate human skin microbiomes within isolated environments, and highlight the necessity for further examinations into the impact of such interactions on skin health.

Location and Surface Materials Drive Differences in Microbial Communities in the Confined HI-SEAS IV Habitat

Fung, K., Ly, H.H., Soriano, S. and Song, C., **2022.** *Undergraduate Journal of Experimental Microbiology and Immunology*, *27*.

Keywords: ***HI-SEAS***, *Microbiology*, *microbial diversity and composition*, *surface materials*, *taxonomic profiles*, *plastics*, *abiotic surfaces*, *functional differences*

Abstract

Humans regularly interact with microbiota on abiotic surfaces promoting its growth or inhibition, which can be well characterized in confined spaces. The Hawaii Space Exploration Analog and Simulation (HI-SEAS) mission IV study examined the microbiome of a confined habitat that simulates the environment in which astronauts will live when sent out on Mars and Moon exploration missions. Indeed, differences in microbial diversity and composition was previously identified between different surface materials, but the effects of surface materials and location on bacterial taxonomic profile and abundances had yet to be explored. Using the collected data from the HI-SEAS IV environment, results showed that microbial taxa on plastic surfaces in three different locations within the habitat had highly conserved taxonomic profiles at the genus-level yet contained significantly different beta diversities and differential abundances. The few unique genera observed from each location is presumed to be due to the functional differences of each area. Notably, both the living room and bedroom compared to the bathroom had significantly higher levels of *Methylophilus*, which are facultative methanol-utilizing bacteria, possibly due to use of disinfecting wipes and hand sanitizers containing toxic methanol contaminants. Bacteria associated with the human microbiome generally dominated the bathroom and bedroom, with many significant genera being associated with the female reproductive tract. In conclusion, considerations should be given to the surface materials and locations within a confined environment when monitoring bacterial communities in enclosed environments.

Comparative Study of Shared Environments Revealed an Increased Microbiome Diversity of Richness and Abundance in Open Environments and Evenness in Closed Environments

Ge, A., Lau, T., Fong, A. and Liu-Fei, F., **2022**. *Undergraduate Journal of Experimental Microbiology and Immunology*, 27.

Keywords: ***HI-SEAS***, *Microbiology*, *human-bacteria interactions*, *shared spaces*, *phylogenetic diversity*, *taxonomic profiles*, *microbial diversity and composition*, *abiotic surfaces*

Abstract

Microbes are ubiquitous organisms that have been familiarly associated with human health and welfare, and human-bacteria interactions can shape the microbial makeup of the broader environment. While there has been extensive research conducted on the human microbiome, few studies have explored human microbiome dynamics as a function of open human social practices, and even fewer studies have explored how confinement parameters as extreme as space exploration simulation can impact the microbiome. Therefore, we aimed to compare two separate datasets modeling an open and confined environment, to investigate whether microbiome diversity differed between the two environments. Our study found that open environments have greater phylogenetic diversity and taxonomic richness at the genus level compared to confined environments, whereas confined environments have greater evenness indices compared to open environments. As a result, we also discovered that the top 20 differentially abundant genera between the datasets were all lower in abundance within our model for confined environments. These findings demonstrate that open and confined environments differ in microbiome diversity.

Influence of Freeze-Dried Diet on Oral Hygiene Indicators in Strict Isolation Condition of an Analog Space Mission

Gronwald, B.J., Kijak, K., Jezierska, K., Gronwald, H.A., Kosko, K., Matuszczak, M., Bielawska-Victorini, H.B., Podraza, W., Orzechowski, L. and Lietz-Kijak, D., **2022**. *International Journal of Environmental Research and Public Health*, *19*(3), p.1367.

Keywords: ***LunAres***, *Microbiology, freeze-dried diet; isolation; oral hygiene; oral health, human-bacteria interactions, API, sOHI, PI, GBI, food, saliva*

Abstract

Analog space missions were created to study the human factor in extraordinary conditions that would occur in future space habitats. Isolation has been shown to cause stress and disrupt individuals' daily routine, which can also affect their oral hygiene and lead to an increased risk of dental caries and gingivitis. The astronauts' specific freeze-dried diet is associated with "lazy" chewing, potential dehydration and vitamin A deficiency, which may adversely affect their saliva. The aim of this study is to investigate the influence of the freeze-dried diet on selected oral hygiene indicators in analog astronauts (AA) enduring strict isolation conditions during six consecutive analog space missions at the LunAres Research Station. During the experiment the oral hygiene and gingival inflammation status measurements were conducted on the group of AAs at the beginning and at the end of each mission. Measurements included four oral hygiene indicators: API, sOHI, PI by Silness and Loe and GBI by Ainamo and Bay. Each AA's individual scores were noted and analyzed. Statistically significant reduction in the amount of plaque and intensity of gingival bleeding was observed over the course of the study, which could indicate positive results of applied oral hygiene procedures despite unfavorable dietary and stressful isolation conditions.

Health, Hygiene, and Microbial Monitoring During Long-Duration Space Simulations

Johnson, B., Sierra-Sastre, Y. and Gifford, S., **2022**. *Acta Astronautica*, *199*, pp.249-258.

Keywords: ***HI-SEAS***, *Microbiology, human-bacteria interactions, food safety, microbiome, microbial monitoring*

Abstract

The significance of the human-microbe relationship is amplified in long duration space exploration (LDSE), where isolated and confined microbial environments degenerate space habitat integrity, compromise planetary protection goals, and have largely unknown and potentially deleterious effects on astronaut health. While environmental surveillance is assumed to be a key component of future deep space missions, the optimal modality, frequency, and location of such surveillance is not yet defined. In order to investigate strategies of microbial surveillance, a series of experiments, conducted at a long-duration, isolated and confined (ICE) Mars simulation, furthered our understanding of the microbiome sampling challenges presented by food, environment, and crewmembers. Descriptive analyses revealed key considerations for microbial monitoring in future long duration space missions, including special considerations for surface sanitation, previously undocumented potential sources of food-borne toxicity, and a novel outlook on the dynamic human microbiome in isolation.

Surface Material and Location Impact Microbial Communities Colonizing Plastic and Wood Surfaces During the HI-SEAS IV Mission

Rajkumar, G., Khan, A., Martens, K. and Park, J., **2022**. *Undergraduate Journal of Experimental Microbiology and Immunology*, 27.

Keywords: ***HI-SEAS***, *Microbiology*, *abiotic surfaces*, *microbial diversity*, *location and functionality*, *plastic*, *wood*, *beta diversity*, *taxonomic composition*, *habitat design*

Abstract

Microbial communities that colonize surfaces have the ability to influence human health and can cause infection and illness. This is an important factor in long-term space travel due to the confined nature of the environment and the frequent interaction between the microbiomes of the crew and surfaces. The Hawaii Space Exploration Analog and Simulation IV study examined the microbial dynamics of crew skin and surfaces on earth that mimicked the isolated and confined environment of Mars and Moon exploration missions. Fluctuations in microbial diversity were found for abiotic surfaces, but the role of surface material and location on microbial community composition had yet to be examined. In our study, we examined how microbial communities changed in relation to surface material and location and found that microbial communities on plastic and wood surfaces showed significant dissimilarities based on beta diversity analysis. From taxonomic bar chart analyses, we found that microbial communities on plastic and wood surfaces had different taxonomic compositions based on surface type and location. Lastly, through assessment of differential abundance analysis at the genus level, we were able to find more differentially abundant taxa on plastic compared to wood. Our study showed that surface material and location did impact microbial community composition and could provide insight when designing environments for future space exploration missions.

Differential Abundance and Metagenome Functional Composition of Microbiomes Suggests Genetic Basis for Survivability of Specific Genera on Plastic and Wood Surfaces in the HI-SEAS IV Built Environment

Shen, J., Chen, A., Xiao, K. and Abdi, I., **2023**. *Undergraduate Journal of Experimental Microbiology and Immunology*, *28*.

Keywords: ***HI-SEAS***, *Microbiology*, *microbial diversity*, *taxonomic composition*, *metagenomics*, *material-specific survival*, *metabolism*, *abiotic surfaces*, *wood*, *plastic*, *microbial resistance*

Abstract

The Hawaii Space Exploration Analog and Simulation Mission was a year-long space isolation study aimed to investigate the effects of space travel and isolation on microbial community composition. Material types used for isolated spacecraft environments have been suggested to select for microbes resistant to extreme environments and sanitation processes, thus creating uniquely resistant populations of microbes. Consideration of changes to isolated microbiomes on abiotic surfaces found within the HI-SEAS environment may provide further insight into their role in the crew's health. In this study we aim to characterize the impact that surface materials have on the diversity of microbial communities found on abiotic surfaces in the HI-SEAS environment, as well as determine if there is a difference in the prevalence of gene families that play a role in microbial survivability on these surfaces. Our results demonstrate an increased microbial diversity between plastic compared to wood surfaces and unique taxonomic community structures between the two surface materials alongside differentially abundant pathways linked to material-specific survival and metabolism.

Can Bulgarian Yogurt Enhance Astronauts' Performance During the Mars Missions?

Shopova, I., Bogueva, D., Yotova, M. and Danova, S., **2023**. *Journal of Ethnic Foods*, *10*(1), p.46.

Keywords: ***MDRS***, *Microbiology*, *probiotics*, *diet*, *gut microbiome*, *digestive system*, *GI tract*, *astronaut health*

Abstract

Probiotics (*pro-for and bio- health*) from yogurt are one of the most effective means to stimulate and strengthen the immune system. They help balance and regulate the digestive system, as well as preserve and enrich the gut microbiome. Maintaining a healthy gut microbiome is crucial for human health and well-being, especially for astronauts living in confined and stressful environments, such as those on a mission to Mars. One way to promote gut microbiome diversity is through diet, and Bulgarian yogurt (kiselo mlyako in Bulgarian: кисело мляко) made with *Lactobacillus delbrueckii subsp bulgaricus* and *Streptococcus thermophilus* has shown positive effects on gut health. This paper explores the potential of regular production and consumption of gut-beneficial foods, such as yogurt, during space travel. It analyses whether the dietary limitations and challenges in providing varied and fresh food for astronauts could be addressed through the addition and daily consumption of Bulgarian yogurt. To investigate this, we conducted an experiment with a team of analog astronauts participating in a two-week analog mission in a closed, Mars-like environment at the Mars Desert Research Station in the Utah desert, the USA. In compliment to all recognized health effects of yogurt, the analog astronauts reported that it can be easily prepared and had a positive effect on their overall well-being and gut health. Our study demonstrated the feasibility of incorporating freshly made yogurt into the astronauts' diet and its potential to significantly contribute to achieving good health and well-being, which is an important goal in the colonization of other planets, such as Mars.

Physiology

Preliminary Study Of The Physiological Demands Of Mars Analogue Extravehicular Activity

Dyson, K.S. and Hughson, R.L., **2005**. In *56th International Astronautical Congress of the International Astronautical Federation, the International Academy of Astronautics, and the International Institute of Space Law* Paper No. IAC-05-A1. 2005:02. (pp. A1-P).

Keywords: ***MDRS***, *Physiology*, *EVAs*, *metabolic cost*, *spacesuit demands*, *aerobic fitness*, *oxygen demand*, *LSS constraints*, *physical fitness*, *gas exchange*

Abstract

The purpose of this study was to investigate the physiological demands of simulated Mars exploration as a first step in determining the physical fitness requirements of interplanetary explorers. The study took place during a geological training mission to the Mars Desert Research Station (MDRS) in Utah, USA. Six crew members were outfitted with a CosMed portable gas exchange analyzer to determine metabolic cost during two hill runs to exhaustion and during at least two extra-vehicular activities (EVA)s while donning an analogue Mars suit. The average VO2 peak during a hill run was 52.4 ± 0.99 ml/kg/min. The peak VO2 reached during a given EVA was 35.87 ± 0.78 ml/kg/min. There was a correlation between aerobic fitness and distance covered during an EVA (R2 =0.34) resulting in a greater demand for oxygen in a given time period for more fit crew members (R2 =0.86). Therefore, we recommend that future simulations use distance covered rather than time elapsed as the criteria for termination of EVA in order to better represent life support constraints. Furthermore, this investigation shows that physiological testing is possible within the framework of current Mars analogue missions, and that further study would be useful in determining both the physical fitness requirements of Marsnauts as well as life support decisions for mission planners. It is hoped that a full-scale study of this type will be included in future science focused Mars analogue expeditions.

Mental and Physical Workload, Salivary Stress Biomarkers and Taste Perception: Mars Desert Research Station Expedition

Rai, B. and Kaur, J., **2012**. *North American journal of medical sciences*, *4*(11), p.577.

Keywords: ***MDRS***, *Physiology*, *amylase*, *cortisol*, *mental workload*, *saliva*, *taste sensation*, *stress*

Abstract

BACKGROUND: Very few studies have been conducted on the effects of simulation of Mars conditions on taste.

AIMS: This study was planned to find the effects of physical and mental workload on taste sensitivity and salivary stress biomarkers.

MATERIALS AND METHODS: Twelve crew members were selected. Taste reactions and intensity of the taste sensations to quinine sulfate, citric acid, and sucrose were tested before and after mental and physical tasks for one hour. Also, psychological mood states by profile of mood state, salivary, salivary alpha amylase and cortisol, and current stress test scores were measured before and after mental and physical tasks.

RESULTS: Average time intensity evaluation showed that after the mental and physical tasks, the perceived duration of bitter, sour, and sweet taste sensations was significantly shortened relative to

control group. There were good correlations between average time intensity of sweetness, bitterness, sourness and cortisol levels.
CONCLUSIONS: Taste alterations due to stress can have an effect on the health and confidence of astronauts in long- term space missions. Thus, this issue remains one of the important issues for future human explorations.

Stress, Workload and Physiology Demand During Extravehicular Activity: A Pilot Study

Rai, B., Kaur, J. and Foing, B.H., **2012**. *North American Journal of Medical Sciences*, *4*(6), p.266.

Keywords: ***MDRS***, *Physiology*, *EVAs*, *cortisol*, *extravehicular activity*, *heart rate*, *peak oxygen uptake*, *saliva*, *stress*

Abstract

BACKGROUND: Extravehicular activity (EVA), such as exercise performed under unique environmental conditions, is essential for supporting daily living in weightlessness and for further space exploration like long Mars mission.
AIM: The study was planned stress, workload, and physiological demands of simulated Mars exploration.
MATERIALS AND METHODS: In this study, the six-person crew lived (24 hours) for 14 days during a short-term stay at the Mars Desert Research Station. The heart rates, salivary cortisol, workload, peak oxygen uptake or maximal aerobic capacity of the crew are measured before, during and after an EVA.
RESULTS: Data for heart rate showed the same trend as peak oxygen uptake or maximal aerobic capacity, with a maximal increase to 85% of peak. The rating of subscale showed a significant increase in EVA as compared to run. Salivary cortisol levels and heart rates were increased in both groups, although significant increase of cortisol levels and heart rates more in EVA as compared to hill running crew members.
CONCLUSION: Further study is required on large scale taken into account of limitations of this study and including other physiological and psychological parameters in Mars analog environment.

Working Hours, Sleep, Salivary Cortisol, Fatigue and Neuro-Behavior During Mars Analog Mission: Five Crews Study

Rai, B., Foing, B.H. and Kaur, J., **2012**. *Neuroscience letters*, *516*(2), pp.177-181.

Keywords: ***MDRS***, *Physiology*, *neurobehavior*, *salivary cortisol*, *working hours*, *sleep*, *leadership*, *cognitive performance*

Abstract

The buoyancy of humans in exploring extreme space environments has been established during missions to the moon. Long duration missions like mission to Mars however, requires humans to adapt to systemic and complex environments beyond the human body's capacity. Astronauts will encounter both physiological and psychological extremes during this trip. Very few studies are conducted on effect of long duration work and sleepiness on cognitive performance. So, this study was planned to find out effects of leadership responsibility, sleepiness and long duration working hours on cognitive performance. The 30 members (leadership: normal; 10:20) were selected from MDRS crews (Mars Desert Research Station, USA). Neurobehavioral test performance, self-ratings of fatigue and sleepiness, and salivary cortisol levels were evaluated during first day, mid and end day of mission. The

leadership group did not show any signs of reduced test performance, even in elevated fatigue and sleepiness. The leadership group had faster reaction times on end of mission as compared to first and after 7 day of mission. Salivary cortisol levels were significantly higher in leadership group as compared to normal group. The results suggest that long duration work and sleepiness does not affect the cognitive performance of crew member. Further study is required while taking into account all factors and large sample size to prove this fact.

Wound Healing and Mucosal Immunity During Short Mars Analog Environment Mission: Salivary Biomarkers and its Clinical Implications

Rai, B., Kaur, J. and Foing, B.H., **2012**. *The Eurasian Journal of Medicine*, *44*(2), p.63.

Keywords: ***MDRS***, *Physiology*, *cortisol*, *wound healing*, *stress*, *IgA*, *IgM*, *IgG*, *saliva*

Abstract

Objective: Wound healing in an extreme environment with micro-gravity is not well characterized, despite the likelihood that the increasing use of manned spaceflight as a research and commercial enterprise raises the probability of traumatic injury in this state. Hence, this study was conducted to determine the impact of the isolated environment of the Mars Desert Research Station on mucosal immunity and wound healing.

Materials and Methods: Two punch biopsy wounds were placed on the hard palate of two crewmembers. The first wound was made during summer vacation, whereas the second was placed on the contra-lateral side 3 days before the Mars analog mission began. Thus, each crewmember served as his/her own control. Two independent methods were used to assess healing. A ten-item perceived stress scale, salivary cortisol, Immunoglobulin A, IgG and IgM were measured.

Results: There were significant differences in the proportion of the wound size healed between vacation and the mission. Salivary IgA, IgM, IgG and cortisol levels showed significant differences between vacation and mission.

Conclusion: These data suggest that stress can have significant consequences for wound healing. The effects of stress on wound repair could have important clinical implications, including for recovery from surgery.

How to Prevent Mind-Wandering During an EVA? Presentation of a Mind-Wandering Detection Method Using ECG Technology in a Mars-Analog Environment

Gontier, C., **2017**. *Acta Astronautica*, *140*, pp.105-112.

Keywords: ***MDRS***, *Physiology*, *EVAs*, *heart rate variability*, *ECG-recordings*, *electro-cardiogram*, *mind-wandering*, *human factors*, *crew performance*, *parasympathetic system*

Abstract

The purpose of this study is to detect mind-wandering in an Extra-Vehicular Activity (EVA) context during a long supervision task. Detection is realized using an electro-cardiogram and measures of heart rate variability. Experienced by everyone, mind-wandering depicts the state of mind where thoughts are not related to the current action. Its deleterious aspect regarding performance suggests a need to take mind-wandering seriously as an impediment to manned space missions' safety. Previous research confirmed the hypothesis according to which several physiological responses can be used to track down mind-wandering. ECG recordings are both easy to obtain and analyze, statistically related to mind-wandering, and easy to record during extra-vehicular activities. Data analyzed in this paper have been recorded during a Mars-analog mission (MDRS 164), from February 20 to March 6, 2016 at the

Mars Desert Research Station (Utah). During various cognitive tasks, the subject had his ECG and awareness levels monitored at the same time to see if a correlation between these two measures can be used in a Mars-mission environment. At different time intervals, the subject was interrupted using the thought probe method to inquire about his thoughts. Heart Rate Variability (HRV, which power in high frequencies is related to the parasympathetic system and is expected to vary with mind-wandering) was then computed from recorded data, and its statistical changes during on-task and off-task thoughts were assessed. Although data revealed no significant differences nor coherent trends in HRV-related metrics between the two conditions, results are paving the way towards a better understanding of ECG-recordings and their use during space-analog missions.

Cardiorespiratory Profiling During Simulated Lunar Mission Using Impedance Pneumography

Młyńczak, M., Kołodziejczyk, A., Krysztofiak, H., Ambroszkiewicz, G., Żyliński, M. and Cybulski, G., **2019**. *Biomedical Signal Processing and Control*, *51*, pp.216-221.

Keywords: ***LunAres***, *Physiology*, *EVAs*, *spacesuits*, *monitoring*, *impedance pneumography*, *cardiorespiratory parameters*, *respiration*, *ECG*, *electro-cardiogram*

Abstract

Manned spaceflight requires research in diverse areas, including neuropsychology and human physiology. For these subjects, the Lunares Analog Research Station was established in Pila, Poland. It allows testing of crew members under space-like conditions. One experiment, Lunar Expedition I, was performed on a group of 6 analogue astronauts over 14 days. All were studied for their subjective perception of time and also asked to carry out mission-specific activities, like digging or repairing a rover during an extravehicular activity (EVA). The aims of the study were to measure cardiorespiratory signals using ECG and impedance pneumography devices under those conditions; to evaluate the quality of the data and the level of motion artefacts; and to assess the subjects' status and adaptation. We used our own prototype, Pneumonitor 2, that enables registering respiratory-related impedance curve, a single-lead ECG and 3-axis accelerometer signals. Due to problems with a detachment of electrodes, we ultimately collected 10 full registrations from 5 astronauts. All signals were pre-processed and annotated. The set of cardiorespiratory parameters, including heart and respiratory activity indicators, was calculated for 3 main states: at rest, doing squats and performing various activities during EVA. We compared the results with normative values collected from elite athletes. The considered parameters were found to be in the normal range, typically slightly worse than the average for the athletes. The physiological responses are in line with expectations. Impedance pneumography enables to measure quantitative parameters of breathing like tidal volume and may be used during dynamic conditions. Combined with the ECG signal provides an objective astronaut's cardiorespiratory profile. One can use it to assess the adaptation and to plan the schedule of the mission. However, there is a need for development of a wearable electronic textile solution for the target electrodes, to deal with sweating occurring while wearing a three-layer EVA suit.

Physiological and Inventory Data of Crews of ARES-III and LEARN Analog Missions in the LunAres Habitat

Bouriat, S., Poliacek, M. and Smith, J., **2021**. In *Global Space Exploration Conference (GLEX 2021)*

Keywords: ***LunAres***, *Physiology*, *nutritional data*, *physiological data*, *medical data*, *weight*, *heart rate*, *blood pressure*, *sleep duration*, *calories burned*, *water consumption*, *waste water*, *hygiene*

Abstract

Analog missions offer a comparatively safe and focused alternative to real human spaceflight missions, thus offering a test and discovery environment for many aspects of future crewed missions to space. In addition, the controlled and often isolated conditions allow to consistently collect a large amount of data that reflect the circumstances and constraints of the analog mission. This paper is a report of the environmental and physiological data from two analog missions that occurred during the summer of 2018 - a Mars analog mission Ares-III and a Lunar analog mission LEARN, both conducted in the same isolated habitat : the Lunares Research Base based in Piła, Poland. Each mission was two weeks long and performed in full isolation from the outside world, with a finite inventory of food and drinking water. Both crews used the same format to track a variety of data categories, consistently doubling the volume of available data. Categories of data collected included nutritional data and daily measurements of physiological and medical data (weight, heart rate, blood pressure, sleep duration and quality) both in the morning and in the evening. The outcomes of daily physical exercise were also collected, including calories burned by running, yoga and strength exercises respectively. Both missions worked with a custom spreadsheet to track their per-crew member food consumption in relation to the mission inventory. This tool also includes automatic calculation of nutrients consumed for each crew member and compares it to the calories burned during the day, thus providing a daily insight into the caloric balance of the crew. Water consumed and expelled was recorded, as well as waste water used for cleaning, personal hygiene and work in the biolab. The consistency of the database thus allows to analyse the data as a whole for both missions, or to compare the effects of aspects differing between the two missions on other human factors. Examples of these include the differences in diets, since LEARN mission provided purely lyophilised food, while ARES-III crew consumed a combination of conventional meals and lyophilised food, or the difference in crew composition, as ARES-III had a crew larger by one member.

Monitoring Human Biomarkers with AO Scan during the First Analog Mission Pilot Study to Build a Biofrequency-based API of Human Body

Lutz, K., Sabry, S., Garcia, K. and Patil, S., **2021**, In *16th International Conference on Space Operations (IAF)*

Keywords: ***LunAres***, *Physiology, bioresonance, CBC human biomarkers, Voice and Body Analysis software, instrument sensitivity*

Abstract

There is a lack of research, access, and understanding of human frequencies and biomarkers derived from bioresonance software. AO Scan is a voice and body analysis software that remotely monitors the electromagnetic and magnetic scalar wave differences in up to 120,000 human frequencies and biomarkers from short scans over a few minutes. In this ground-based pilot study, 90 non-invasive Vitals and Comprehensive Scans were conducted on a six-person crew during a two week Analog Mission at the LunAres research station in Poland. Complete blood count (CBC) biomarkers from six Vitals scans were recorded for each analog astronaut and compared to two blood tests from February 12 and 26, 2021. With six analog astronauts generating 3,600 biomarkers per Vitals scan each day, the study analysed the accuracy of 0.833% of the 54,000 biomarkers generated from the Vitals Scan. The first data analysis yielded an accuracy of 65% in describing both the in and out of range CBC biomarkers. A high false positive rate of 76.9% was observed, as well as a false negative rate of 30.1%, a true negative rate of 23.1%, and a true positive rate of 69.3%. The second data analysis determined how many CBC biomarkers deviated under 30 or over 70 percent from the maximum healthy CBC biomarker range. The study results are largely inconclusive considering a variety of reasons including instrument sensitivity, time differences, small sample size, diet, and environmental factors. This experiment represents the first peer reviewed study to use the bioresonance non-linear scanner AO

Scan to remotely monitor the health of humans and analog astronauts. Further research is required to quantify the accuracy and efficacy of AO Scan by comparing them with established medical diagnostic tools in order to understand the potential significance in monitoring human health.

Evaluation of Physiotherapy Impact on Neuromuscular Tension in Analog Astronauts at the LunAres Habitat

Gronwald, B., Kijak, K., Baszuk, P., Lietz-Kijak, D., Kosko, K., Matuszczak, M., Skomro, P., Bielawska-Victorini, H., Orzechowski, L., Mintus, A. and Gronwald, H., **2022**. *International Journal of Environmental Research and Public Health*, *19*(11), p.6888.

Keywords: ***LunAres***, *Physiology, neuromuscular tension, trigger point therapy, TMD, TMJ diagnosis, stress, isolation, ischemic compression*

Abstract

The evaluation of manual Trigger Point Therapy (TrPt) on mandible abduction range of Analog Astronauts (AA) surviving isolation conditions during consecutive missions at the LunAres Habitat was performed. This physiotherapy method was applied to decrease stress-related neuromuscular tension. Abduction measurements were conducted on the two groups of five AA, who endured severe isolation conditions for 14 days in the limited space of the LunAres Research Station Habitat (Piła, Poland) during missions. The test group consisted of abduction measurements of AA who received TrPt and control group of abduction measurements of AA who did not receive TrPt. All measurements were noted in the TemporoMandibular Joint (TMJ) diagnosis aspect of the integrated dental examination card SZOPPDP©. The ischemic compression was performed on an active localized trigger point—resulting in cessation of pain. Maximum abduction measurements were made with an electronic caliper, and the abduction range was compared. The change of abduction range in AA with TrPt was bigger than in AA without TrPt. A larger increase in abduction range was observed in every case in the group receiving TrPt compared to the control group. TrPt effectively decreases the neuromuscular tension, which results in an increased mandibular abduction range of AA. Observations conducted in LunAres Research Station regarding stress-related neuromuscular tension can help identify effective therapeutic methods for circumstances of social isolation.

Robotics and Rovers

Comparative Field Tests of Pressurised Rover Prototypes

Mann, G.A., Wood, N.B., Clarke, J.D., Piechocinski, S., Bamsey, M. and Laing, J.H., **2004**. *Journal of the British Interplanetary Society*, *57*(3-4), pp.135-143.

Keywords: ***MDRS***, *Rovers*, *pressurised rover*, *prototypes*, *conceptual design*, *operational performance*, *operational protocols*, *field-testing*

Abstract

The conceptual designs, interior layouts and operational performances of three pressurised rover prototypes - Aonia, ARES and Everest - were field tested during a recent simulation at the Mars Desert Research Station in Utah. A human factors experiment, in which the same crew of three executed the same simulated science mission in each of the three vehicles, yielded comparative data on the capacity of each vehicle to safely and comfortably carry explorers away from the main base, enter and exit the vehicle in spacesuits, perform science tasks in the field, and manage geological and biological samples. As well as offering recommendations for design improvements for specific vehicles, the results suggest that a conventional Sports Utility Vehicle (SUV) would not be suitable for analog field work; that a pressurised docking tunnel to the main habitat is essential; that better provisions for spacesuit storage are required; and that a crew consisting of one driver/navigator and two field science crew specialists may be optimal. From a field operations viewpoint, a recurring conflict between rover and habitat crews at the time of return to the habitat was observed. An analysis of these incidents leads to proposed refinements of operational protocols, specific crew training for rover returns and again points to the need for a pressurised docking tunnel. Sound field testing, circulating of results, and building the lessons learned into new vehicles is advocated as a way of producing ever higher fidelity rover analogues.

Desert FLEAS: Field Tests of EVA/Robotic Collaborative Planetary Geological Exploration

Akin, D.L., Saripalli, S., Hodges, K., Young, K., Davis, K., Salmoiraghi, A. and Di Capuaz, M., **2013**. In *43rd International Conference on Environmental Systems*, *ICES 2013*.

Keywords: ***HI-SEAS***, *Robotics*, *rovers*, *geology*, *Cooper-Harper rating*, *geological exploration*, *planetary surfaces*, *quantitative data*, *subjective evaluations*, *terrain challenges*, *NASA Task Load Index*, *survey rovers*

Abstract

The paper serves as a mid-program review for the Desert Field Lessons in Engineering and Science (Desert FLEAS), a joint University of Maryland/Arizona State University in vestigation of collaborative EVA/robotic geological exploration of planetary surfaces. After a brief synopsis of three prior field series and discussion of lessons learned to date, this paper details plans for the last two tests in planned series: Desert FLEAS IV tests, scheduled for autumn, 2013 in northern Arizona, and Desert FLEAS V in spring 2014 in southern Arizona. These sites represent an order of magnitude increase in the terrain challenges for both the human subjects and the RAVEN support rover, with deep ravines frequently obstructed by rockfalls. The upcoming test series will focus on extended (multisite, multikilometer) traverses by single and paired EVA subjects, in conjunction with the revised and upgraded RAVEN support rover. Detailed test objectives will include the use of smaller survey rovers to

assess upcoming transit routes and provide preliminary scouting prior to human arrival, as well as the experimental use of alternate technologies to reach rock sampling sites not accessible by simple walking or climbing in the space suit simulators. Quantitative data will be collected by the BPMS and in-suit metabolic workload systems based on oxygen uptake and CO_2 production, as well as standardized subjective evaluations including Cooper-Harper ratings and NASA Task Load Index studies. The paper also summarizes collaborations with the HI-SEAS analogue studies in Hawaii, which has adopted the UMd space suit simulators for EVA operations, and ends with a discussion of the value of an ongoing series of field analogue simulations.

Mongol Barota: A Next Generation Rover

Shafin, M.K., Kabir, K.L., Ridwan, I., Fuad, T.A., Bardhan, S., Raju, M.I.H., Tahira, A., Afrin, I., Mondal, S., Tumpa, S.N. and Ahmed, A., **2014**, In *The 8th International Conference on Software, Knowledge, Information Management and Applications (SKIMA 2014)* (pp. 1-8). IEEE.

Keywords: ***MDRS***, *Rovers, system architecture, rover facts and features, rover system components, logic, rover logistics, rover operability, equipment servicing, terrain traversing, astronaut assistance, sample return,*

Abstract

This paper scrutinizes Mongol Barota - a fully functional, stand-alone mobile platform rover which is capable to act as a human assistant to perform various scientific tasks in extreme adversities. The control system of the rover is designed in such a way that it can be commanded from a blind station within 1 kilometer range. It has successfully taken part in 8th annual University Rover Challenge organized by the Mars Society at the Mars Desert Research Station (MDRS) in the remote, barren desert of southern Utah, USA in late May, 2014. It has been traced out as the first entrance in this competition from Bangladesh and occupied 12th position out of 31 registered teams from 6 countries of 4 continents. The rover architecture maps the associated components to make it capable to perform the assigned tasks namely - Sample Return Task, Astronaut Assistance Task, Equipment Servicing Task and Terrain Traversing Task. Among these, the first task refers to search for the evidence to identify the existence of life after detailed analysis of collected soil sample from a selected site. In Equipment servicing task, rover has to perform a sequence of operations that mainly includes switching on a compressor and working with a series of pipes, hoses, valves and other such equipment. Astronaut assistance task intends the rover to collect tools from some given GPS locations and then delivery of each of them to the corresponding locations with provided GPS coordinates. Rover has to traverse an adverse terrain in order to pass through a set of target gates for completion of the terrain traversing task. This paper provides a detailed demonstration of the Mongol Barota rover, ins and outs of its architecture, facts and features, system components, logic, logistics and techniques adopted to implement several tasks representing its overall capabilities.

The Cliff Reconnaissance Vehicle: A Tool to Improve Astronaut Exploration Efficiency

Souchier, A., **2014**. *Astrobiology*, *14*(5), pp.406-416.

Keywords: ***MDRS***, *Rovers, astrobiology, cliffs, geology, robotics, field assistance, imaging, mapping, life-detection*

Abstract

The close examination of cliff strata on Mars may reveal important information about conditions that existed in the past on that planet. To have access to such difficult-to-reach locations, the Association Planète Mars (France) has, since 2001, been experimenting with designs of manually operated, instrumented vehicles capable of being lowered down the faces of cliffs. The latest tests in the series in

which the Cliff Reconnaissance Vehicle (CRV) or Cliffbot was used were conducted as part of the Austrian Space Forum's MARS2013 field analog project in Morocco in February 2013. Experimentation centered on vehicle configuration for maximum all-terrain capabilities; operational procedures, which included use while the operator was wearing an analog space suit; and imaging, mapping, and geological/biological feature detection capabilities. The exercise demonstrated that Cliffbot is capable of examining hard-to-reach rock strata in cliff faces but that it needs further mechanical modification to improve its ability to overcome some particular terrain obstacles and situational awareness by the operator.

Small Rover Exploration Capabilities

Salotti, J.M., Laithier, C., Machut, B., Marie, A., Bruneau, A., Grömer, G. and Foing, B.H., **2015**. *Advances in Space Research*, *55*(10), pp.2484-2491.

Keywords: ***MDRS***, *Rovers, human-robotic performance, human centered design, EVAs, small surface vehicles, unpressurized vehicles*

Abstract

For a human mission to the Moon or Mars, an important question is to determine the best strategy for the choice of surface vehicles. Recent studies suggest that the first missions to Mars will be strongly constrained and that only small unpressurized vehicles will be available. We analyze the exploration capabilities and limitations of small surface vehicles from the user perspective. Following the “human centered design” paradigm, the team focused on human systems interactions and conducted the following experiments:
– The Austrian Space Forum (OeWF) coordinated a Mars analog research program in Morocco in February 2013. During this 23-nation expedition, we studied surface mobility aspects in challenging terrains also to be expected on Mars. Two test subjects in high-fidelity spacesuit simulators and driving All-Terrain Vehicles (ATV, aka quads) had to traverse various obstacles found in a desert region and answer a list of questions about their vehicle, the obstacles and possible options to go further.
– Another member of our team participated in the ILEWG EuroMoonMars 2013 simulation at the Mars Desert Research Station in Utah during the same period of time. Although the possible traverses were restricted, a similar study with analog space suits and quads has been carried out.
– Other experiments have been conducted in an old rock quarry close to Bordeaux, France. An expert in the use of quads for all types of terrains performed a demonstration and helped us to characterize the difficulties, the risks and advantages and drawbacks of different vehicles and tools.
The vehicles that will be used on the surface of Mars have not been defined yet. Nevertheless, the results of our project already show that using a light and unpressurized vehicle (in the order of 150 kg) for the mobility on the Martian surface can be a true advantage. Part of the study was dedicated to the search for appropriate tools that could be used to make the vehicles easier to handle, safer to use and more efficient in the field to cross an obstacle. The final recommendation is to use winches and ramps, which already are widely used by quad drivers. We report on the extension of the reachable areas if such tools were available.
This work has been supported by ILEWG, EuroMoonMars and the Austrian Space Forum (OEWF).

Safety Systems in Rover Controller

Andrzejczak, K., **2017**. *World Scientific News*, *1*(73), pp.34-42.

Keywords: ***MDRS***, *Robotics, rovers, controller, communication, mobile robot, remote driving, safety, UDP protocol, computing power*

Abstract

This study's objective was to determine the level of safety measures used in mobile robot prepared for teleoperation tasks in long distances and harsh environment. The vehicle under test was six-wheeled Mars rover equipped with robotic arm, designed to compete in URC (University Rover Challenge). The analysis has been subjected to the following: communication system, performance of onboard computer and emergency stop system. Communication system has been tested for message exchange speed under various data transmission protocols. Link between base station and mobile robot has immediate influence on onboard computer performance. Emergency stop is an indispensable part of hardware and software, it was tested in different state of the robot to ensure it robustness. This study demonstrates that for the teleoperation control, the UDP protocol is suitable for communication while at the same time allows to maintain low usage of a computing power at the on-board computer.

Science and Exploration of the Moon Enabled By Surface Telerobotics

Seedhouse, E.L. and Llanos, P., **2021**. *Journal of Space Safety Engineering*, *8*(3), pp.231-237.

Keywords: ***LunAres***, *Robotics*, *rovers*, *telerobotics*, *pre-mission planning*, *site surveys*, *surface asset deployment*, *crew workload*, *crew situation awareness*, *robot asset acquisition*, *task sequence success*, *system issues*, *rover performance*, *interactive monitoring*, *task loading*

Abstract

Tele-operated rovers have been a feature of space exploration for decades. Ground control teams that operate these rovers generally comprise a robot operations team supported by science and robot engineering groups. But, in the future, astronauts will also remotely operate rovers. Several studies have proposed that astronauts should be able to control rovers from orbiting spacecraft such as the Deep Space Gateway (DSG). This concept of operations offers several benefits to human exploration. Firstly, it will enable astronauts to expand their sphere of influence beyond the confines of a spacecraft. Secondly, it will enable astronauts to safely perform surface work via an avatar. Thirdly, it will reduce the expenditure of life support consumables, and fourthly, it will spare astronauts from spending time on radiation-ravaged planetary surfaces. But integrating tele-operated rovers into human space exploration raises important questions. What system configurations are effective? Which modes of operation and control are most appropriate? When is it appropriate to rely (or not) on tele-operated rovers? The proposed research sought to answer the first two of these questions. It was designed to simulate three mission phases: pre-mission planning, site survey, and surface asset deployment. The study employed a derived terrain model located in the LunAres hab facility (located in Pila, Poland). Operators drove a Turtle rover through task sequences to survey sites while avoiding hazards/obstacles. This study simulated remote rover operations that assessed crew workload, crew situation awareness, robot asset acquisition, task sequence success, system issues, and rover performance. This study demonstrated basic competence in teleoperated rover driving, but more work must be conducted to produce a system that can behave reliably over many weeks and/or kilometers. Results indicated interactive monitoring is an effective strategy for crew-centric surface telerobotics. Safeguarded driving using this mode of operation enabled participants to perform each task successfully – success being measured by the metric of completing assigned tasks and completing the course. Participants maintained good situational awareness (SA) with low effort using interactive visualization of the rover state. From post-test debriefs it was determined participants maintained a high level of SA during operations and that the activity employed via the operator interface was a contributing factor to achieving these high levels. Since the test sessions were designed to be increasingly difficult in terms of task complexity it was expected that SA would decrease and task loading would increase across tasks and the data confirms this was the case.

Technology

The Mobile Agents Integrated Field Test: Mars Desert Research Station April 2003

Clancey, W.J., Sierhuis, M., Alena, R., Crawford, S., Dowding, J., Graham, J., Kaskiris, C. and Tyree, K.S., **2003**. In *FLAIR 2004*.

Keywords: ***MDRS***, *Technology*, *software*, *distributed architecture*, *navigation*, *surface operations*, *GPS*, *health data*, *voice commands*, *EVAs*, *comms*, *engineering*, *communication protocols*, *NASA*

Abstract

The Mobile Agents model-based, distributed architecture, which integrates diverse components in a system for lunar and planetary surface operations, was extensively tested in a two-week field "technology retreat" at the Mars Society's Desert Research Station (MDRS) during April 2003. More than twenty scientists and engineers from three NASA centers and two universities refined and tested the system through a series of incremental scenarios. Agent software, implemented in runtime Brahms, processed GPS, health data, and voice commands-monitoring, controlling and logging science data throughout simulated EVAs with two geologists. Predefined EVA plans, modified on the fly by voice command, enabled the Mobile Agents system to provide navigation and timing advice. Communications were maintained over five wireless nodes distributed over hills and into canyons for 5 km; data, including photographs and status was transmitted automatically to the desktop at mission control in Houston. This paper describes the system configurations, communication protocols, scenarios, and test results.

IP Telephony for Interplanetary Exploration

Stone, T., Alena, R. and Johnson, M., **2004**. In *2004 IEEE Aerospace Conference Proceedings (IEEE Cat. No. 04TH8720)* (Vol. 2, pp. 1217-1230). IEEE.

Keywords: ***MDRS***, *Technology*, *telecom*, *telephony*, *voice over IP*, *VoIP*, *comms*, *communications*, *wireless LAN concepts*, *telephone*, *internet*, *data applications*

Abstract

Voice over IP (VoIP), using techniques developed for telephony, is a natural method for providing voice services for planetary explorers. Providing the ability to make telephone calls over the Internet, VoIP can replace radiofrequency communications in remote environments that are not serviced by a conventional telephone system. VoIP can provide better quality voice than either analog radio or conventional phone. As another benefit, VoIP enables the integration of voice and data applications, thus eliminating the need for separate frequency management and antenna systems. This paper provide an overview of IP telephony and wireless LAN concepts and examine VoIP applicability for planetary exploration. The use of VoIP at the Mars Desert Research Station (MDRS) be evaluated. Benefits be highlighted and additional features that would be desirable to incorporate with VoIP be discussed. The paper conclude with a discussion of VoIP studies that be conducted by the NREN group in the future.

Evaluation of a surface exploration traverse analysis and navigation tool

Gilkey, A., Kobrick, R., Galvan, R., Johnson, A., Hoffman, J., Newman, D. and Melo, P., **2011**. In *41st International Conference on Environmental Systems* (p. 5181).

Keywords: ***MDRS***, *Technology*, *mission planning*, *software*, *MATLAB*, *EVAs*, *energy consumption*, *contingency planning*, *navigation*

Abstract

SEXTANT is an extravehicular activity (EVA) mission planner tool developed in MATLAB, which computes the most efficient path between waypoints across a planetary surface. The traverse efficiency can be optimized around path distance, time, or explorer energy consumption. The user can select waypoints and the time spent at each, and can visualize a 3D map of the optimal path. Once the optimal path is generated, the thermal load on suited astronauts or solar power generation of rovers is displayed, along with the total traverse time and distance traveled. A field study was conducted at the Mars Desert Research Station (MDRS) in Utah to see if there was a statistical difference between the SEXTANT-determined energy consumption, time, or distance of EVA traverses and the actual output values. Actual traverse time was significantly longer than SEXTANT-predicted EVA traverse time (n=6, p<0.01), traverse distance was not significantly different than SEXTANT-predicted distance, and explorer energy consumption was significantly greater than SEXTANT-predicted energy consumption (n=5, p<0.01). A second study was done to see if mission re-planning, or contingency planning, was faster and less work when using SEXTANT in the habitat or in the field using an iPad. Time and workload measurements were collected for each subject under both conditions. Contingency planning in the habitat was not significantly different than contingency planning in the field. There was no significant workload difference when contingency planning in either location, however there was a trend that suggested contingency planning was faster in the habitat (n=3, p=0.07). Every subject commented that it was a hassle to carry the mission planner in the field and it was difficult to see the screen in the sunlight. To determine if gloves were a factor in the difference between mission re-planning time, subjects were asked to plan a contingency indoors with and without gloves. Performance and workload were not significantly different when re-planning with and without the gloves. The SEXTANT mission planner will continue to be improved according to the results and the recommendations of subjects in this study.

Wearables Data Integration: Data-driven Modeling to Adjust for Differences in Jawbone and Fitbit Estimations of Steps, Calories, and Resting Heart-rate

Shah, Y., Dunn, J., Huebner, E. and Landry, S., **2017**. *Computers in Industry*, *86*, pp.72-81.

Keywords: ***HI-SEAS***, *Technology*, *data integration*, *wearables*, *Jawbone*, *Fitbit*, *database design*, *standardization*, *step-count*, *heart rate measurements*, *astronaut health*, *medical data*

Abstract

Differences in data output from two leading devices in the consumer-grade wearables market have been examined, namely Jawbone UP4 and Fitbit Charge HR devices, by comparing measurements that were conducted while participants wore both devices in tandem. Aggregate daily totals of steps and calories were shown to be highly correlated between devices (0.82–0.93 correlation coefficient for steps and 0.71–0.85 for calories); however, at the hourly level, differences in data output are evident, especially during hours of vigorous activity. These differences lead to both under- and over-estimation of measures such as hourly step-counts. Heart rate measurement with Jawbone and Fitbit is shown to be significantly different even at the daily level (p-value < 0.00001), which could be due to hardware differences in sensor type and possibly due to unknown differences in proprietary algorithms. Models

were trained to enable adjustment of data collected from one device to the equivalent value in terms of the other device's measurement. This approach to data integration is recommended for researchers who are comparing data from multiple wearable devices, for individual users who have switched from one device to another and could use this method to adjust their wearables data history to be comparable with the new device, or for users who are comparing data with a user who has another type of device, or for groups organizing fitness challenges and health initiatives that can track users by comparing diverse wearables data.

30 Sensors to Mars: Toward Distributed Support Systems for Astronauts in Space Habitats

Rüb, I., Matraszek, M., Konorski, P., Perycz, M., Waśniowski, A., Batorski, D. and Iwanicki, K., **2019**. In *2019 IEEE 39th International Conference on Distributed Computing Systems (ICDCS)* (pp. 1704-1714).

Keywords: ***LunAres***, *Technology*, *sensors*, *sociometrics*, *distributed systems*, *ergonomics*

Abstract

In October 2017, an international crew participated in an emulated Mars colonization mission. For two weeks, they stayed confined in a special complex, a so-called analog habitat, where they were isolated from the outside world, including a lack of natural lighting and exterior noises, and lived on particularly adjusted Martian time. The mission followed a strict schedule, involving actual scientific work and activities envisioned as necessary for survival and exploration of the red planet. The main objective was to study the behavior and group dynamics of the crew in conditions recreating colonization of Mars, albeit under some unique circumstances compared to previous similar experiments. What was also special about the mission was the use of sociometric methods utilizing custom pervasive sensing solutions that we had built and deployed to complement classic methods based on self-reports and interviews. Based on that experiment, in this paper we contribute twofold. First, we share our deployment experiences to highlight the potential of pervasive distributed sensing systems in sociometric studies of habitat-based missions. The examples presented to this end include quantitative results that we obtained, among others, on social interactions between the astronauts, the impact of atypical situations on the crew, and the ergonomics of the habitat. Second, drawing from the experiences, in cooperation with the astronauts we attempt to highlight some unique challenges that space habitats pose for distributed support systems, such as ours. Among others, the challenges pertain to system deployment, autonomy, resilience, and flexibility. We believe that these challenges and, in general, space colonization constitute exciting research opportunities for the distributed systems community.

A Portable Miniaturized Laser Heterodyne Radiometer (mini-LHR) for Remote Measurements of Column CH_4 and CO_2

Wilson, E.L., DiGregorio, A.J., Villanueva, G., Grunberg, C.E., Souders, Z., Miletti, K.M., Menendez, A., Grunberg, M.H., Floyd, M.A.M., Bleacher, J.E. and Euskirchen, E.S., **2019**. *Applied Physics B*, *125*, pp.1-9.

Keywords: ***HI-SEAS***, *Technology*, *physics*, *methane*, *carbon dioxide*, *passive laser heterodyne radiometer*, *radio frequency*, *portable instrumentation*, *chemistry*, *gas leaks*

Abstract

We present the design of a portable version of our miniaturized laser heterodyne radiometer (mini-LHR) that simultaneously measures methane (CH_4) and carbon dioxide (CO_2) in the atmospheric column. The mini-LHR fits on a backpack frame, operates autonomously, and requires no

infrastructure because it is powered by batteries charged by a folding 30 W solar panel. Similar to our earlier instruments, the mini-LHR is a passive laser heterodyne radiometer that operates by collecting sunlight that has undergone absorption by CH_4 and CO_2. Within the mini-LHR, sunlight is mixed with light from a distributive feedback (DFB) laser centered at approximately 1.64 µm where both gases have absorption features. The laser scans across these absorption features roughly every minute and the resulting beat signal is collected in the radio frequency (RF). Scans are averaged into half hour and hour data products and analyzed using the Planetary Spectrum Generator (PSG) retrieval to extract column mole fractions. Instrument performance is demonstrated through two deployments at significantly different sites in interior Alaska and Hawaii. The resolving power ($\lambda/\Delta\lambda$) is greater than 500,000 at 1.64 µm with precisions of better than 20 ppb and 1 ppm for CH_4 and CO_2, respectively. Because mini-LHR instruments are portable and can be co-located, they can be used to characterize bias between larger, stationary, column observing instruments. In addition, mini-LHRs can be deployed quickly to respond to transient events such as methane leaks or can be used for field studies targeting geographical regions.

A Portable Muon Telescope Based on Small and Gas-Tight Resistive Plate Chambers

Wuyckens, S., Giammanco, A., Cortina Gil, E. and Demin, P., **2019**. *Philosophical Transactions of the Royal Society A*, *377*(2137), p.20180139.

Keywords: ***MDRS***, *Technology*, *physics*, *instrumentation*, *muography*, *miniaturisation*, *portable*, *detector*

Abstract

We report on the first steps in the development of a small-size muon telescope based on glass resistive plate chambers with small active area (16×16 cm^2). The long-term goal of this project is to focus on applications of muography where the telescope may have to be operated underground and/or inside small rooms, and in challenging logistic situations. Driving principles in our design are therefore compact size, light weight, gas tightness and robustness. The first data-taking experiences have been encouraging, and we elaborate on the lessons learnt and future directions for development.

Enabling Astronaut Self-Scheduling Using a Robust Advanced Modelling and Scheduling System: An Assessment During a Mars Analogue Mission

Saint-Guillain, M., Vanderdonckt, J., Burny, N., Pletser, V., Vaquero, T., Chien, S., Karl, A., Marquez, J., Wain, C., Comein, A. and Casla, I.S., **2023**. *Advances in Space Research*, 72(4), pp. 1378-1398

Keywords: ***MDRS***, *Technology*, *software*, *scheduling*, *modelling*, *computation*, *autonomy*, *operations management*

Abstract

Human long duration exploration missions (LDEMs) raise a number of technological challenges. This paper addresses the question of the crew autonomy: as the distances increase, the communication delays and constraints tend to prevent the astronauts from being monitored and supported by a real time ground control. Eventually, future planetary missions will necessarily require a form of *astronaut self-scheduling*. We study the usage of a computer decision-support tool by a crew of analog astronauts, during a Mars simulation mission conducted at the Mars Desert Research Station (MDRS, Mars Society) in Utah. The proposed tool, called *Romie*, belongs to the new category of *Robust Advanced Modelling and Scheduling* (RAMS) systems. It allows the crew members (i) to visually model their scientific objectives and constraints, (ii) to compute near-optimal operational schedules while taking uncertainty into account, (iii) to monitor the execution of past and current activities, and (iv) to modify scientific objectives/constraints w.r.t. unforeseen events and opportunistic science. In this

study, we empirically measure how the astronauts, who are novice planners, perform at using such a tool when self-scheduling under the realistic assumptions of a simulated Martian planetary habitat.