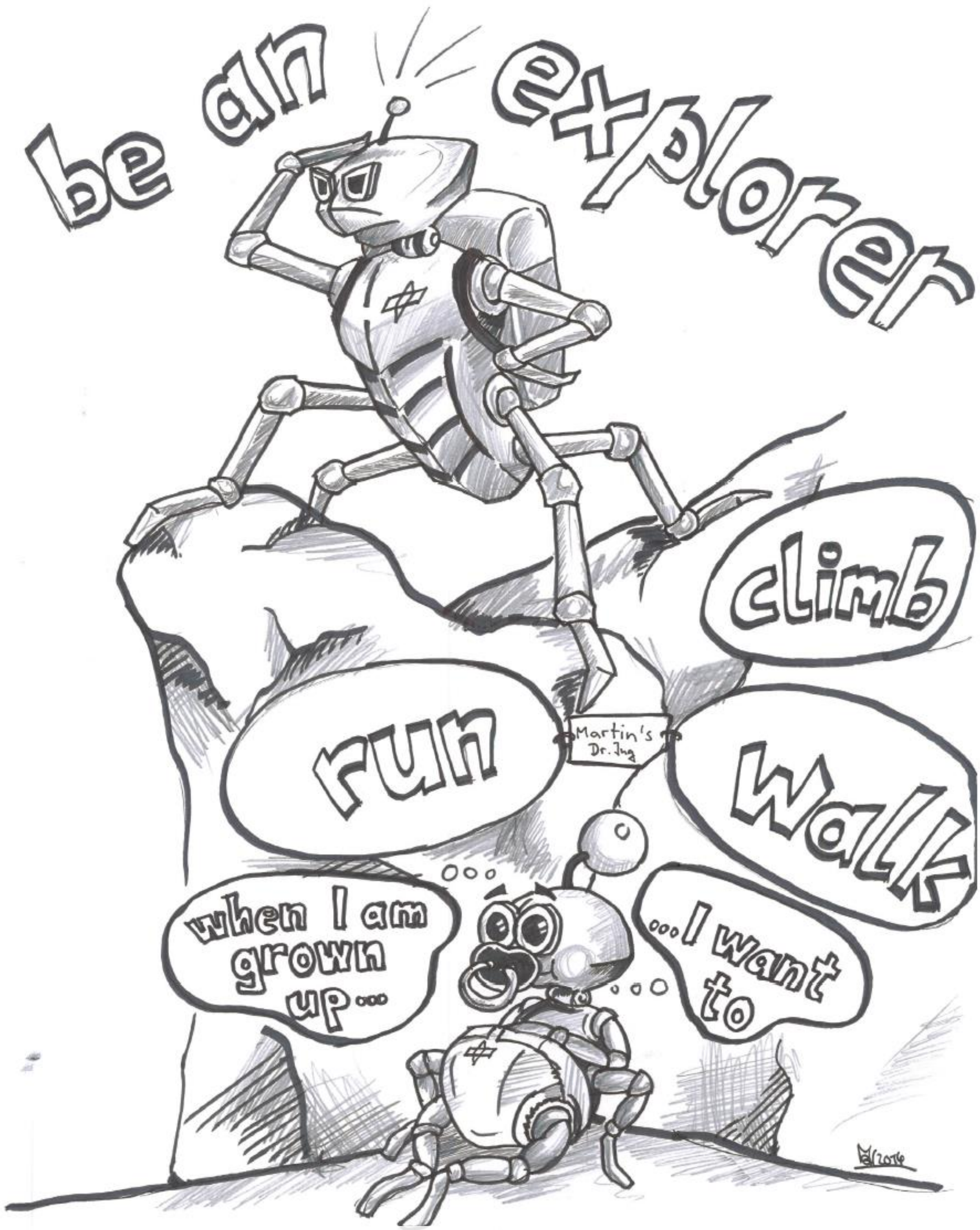
ROBEX Alliance
Newsletter – Special Issue



2nd Robex Training Workshop

2nd ROBEX Training Workshop

Pedro de Jesus Mendes

The 2nd Training Workshop (TW) was organized by Jacobs University Bremen with the collaboration of the DFKI and TU-Dresden, and took place both during the venue of the Community Workshop, and in the TU-Dresden facilities, in Dresden, from the 19th to the 20th of March 2014.

We had seventeen participants from six different institutions (AWI, DLR, TU-Berlin, TU-Dresden, TU-München and University of Würzburg).

The training was coordinated by five lecturers from 3 partner institutions (DFKI, DLR, Jacobs University Bremen).

Some of the participants of the 2nd ROBEX Training Workshop at TU-Dresden.

The scope and form of the 2nd TW was based on the feedback from the 1st TW. That feedback showed a demand for a more practical approach to the training, while staying very close to the stated objectives of the Alliance to inspire a diversity of discussion and cross-fertilization of ideas.

An anonymous online questionnaire was provided to the participants after the event, to evaluate the TW using a graded scale of 3 positive options (Extremely -, Quite - or Somewhat -), a neutral option (Neither- or -) and 3 negative options (Somewhat -, Quite - or Extremely -) .

Poster session

The TW initiated with a poster session, in which the trainees presented to the general community posters detailing their recent research. During this session the trainees had the chance to train their presentation and discussion skills, as well as their ability to critically evaluate their colleagues work. The trainees were exposed to each other's research, including topics diverse as systems engineering and power management, simulations, visualization and interfaces, autonomy, sensors and instrumentation or analysis of large datasets. The reader can find this interesting research in the next pages.

Of the trainees evaluating the TW, 54% considered this approach "Quite helpful" or "Very helpful" and 36% considered it "Somewhat helpful"

The Poster Session Awards of the 2nd ROBEX Training Workshop went to:

Community Award - Caroline Lange "Analysis of modularity and product platforming principles for lunar infrastructures"

Trainees Award - Etienne Dumont "Transportation Systems for Modular Robotic Moon Infrastructure"

Training session

Moving to the facilities of TU-Dresden, the trainees were welcomed and promptly introduced to a specially prepared online course on transect analysis and statistics by Autun Purser.

The trainees were then divided into groups, and rotated through the different training modules.

This year's workshop was more focused on the practical aspect of Ocean and Space Sciences. When inquired on it, 100% of the responses were positive, with 91% responding they were “Quite satisfied” or “Extremely satisfied”.

The modules included the outline of available online databases, which can be useful for many of the ROBEX related disciplines. A very large amount of data is available online, and can be freely used e.g. for choosing deployment locations, to select real in situ parameters for simulations or to understand environmental demands and variations.

The trainees were introduced to online databases in Ocean Sciences, and the possibilities available for data treatment and display. The students were introduced to online data visualization tools that are extremely helpful for the selection of data and periods to download. 60% rated this module “Quite interesting”, while 40% rated it “Extremely interesting”. This module was guided by Laurenz Thomsen (Jacobs) and Autun Purser (Jacobs).

In the same vein, the trainees were introduced to different online databases for Space Science. The trainees were instructed how to select and download moon related data. The analysis of the selected environmental data was performed using online tools for data visualization. 40% rated this module “Quite interesting”, while 60% rated it “Extremely interesting”. This module was guided by Marlene Bamberg (DLR).

One of the groups analysing Moon data obtained from online databases.

Transect analysis is a very versatile tool available to scientists working with deployed vehicles. In this year’s TW the trainees undertook an analysis of a Deep-Sea video transect for fauna numbers and behavior under different conditions, meant for later statistical analysis. 30% of the respondents classified this module as “Extremely interesting”, while 50% classified it as either “Quite interesting” or “Somewhat interesting”. 20% classified this module as either “Somewhat uninteresting” or “Quite uninteresting”. This module was guided by Pedro de Jesus Mendes (Jacobs) and Laurenz Thomsen (Jacobs).

To illustrate the potential of transect analysis in the Space Sciences the trainees undertook an analysis of a Moon video transect, for later statistical analysis. 30% of the respondents classified this module as “Extremely interesting”, while 50% classified it as either “Quite interesting” or “Somewhat interesting”. 20% classified this module as either “Somewhat uninteresting” or “Quite uninteresting". This module was guided by Frank Sohl (DLR) and Marlene Bamberg (DLR).

Scientists are not always aware of the physical limitations and handling difficulty of the vehicles they work with. The trainees had the opportunity to drive the DFKI's ROV Asguard through an obstacle course in TU Dresden. 30% found it "Extremely interesting", while 50% found it to be "Quite interesting". 20% of the respondents found this module "Somewhat interesting" or "Neither interesting nor uninteresting". This module was guided by Alexander Duda (DFKI) and Pedro de Jesus Mendes (Jacobs).

The trainees also had the opportunity to drive Jacob University's IOV Wally, live in the Neptune Canada site. 80% of the respondents found this module "Extremely interesting", while 20% found it either "Quite interesting" or "Somewhat interesting". This module was guided by Laurenz Thomsen (Jacobs).

Trainees driving the Jacobs Internet operated vehicle live in the Pacific coast of Canada, at 900m depth.

The trainees were introduced to an online course on biostatistics and transect analysis. They used the data they collected to perform statistical tests, including ANOVA, while being introduced to online statistical tools. 30% of the respondents classified this module as "Extremely interesting", while 50% classified it as either "Quite interesting" or "Somewhat interesting". 20% classified this module as either "Neither interesting nor uninteresting " or "Somewhat uninteresting". This module was guided by Autun Purser (Jacobs).

One of the trainees driving the DFKI vehicle ASGUARD.

Overall, when inquired about their satisfaction with the TW, the feedback was 100% positive, with 64% responding they were "Quite satisfied" or "Extremely satisfied". From the technical requirements there is a lot of resemblance to aircraft construction. As the HGF alliance ROBEX is bringing together research groups from the area of the deep-sea research and the aviation and space a unique opportunity is offered to work together on forward looking, robotic systems.

On the cover: Illustration by Martin Görner

The ROBEX Alliance Newsletter is non-periodical - if you have items to contribute to the next issue, please send them to p.mendes@jacobs-university.de

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ROBEX Allianz

HGF Alliance ROBEX
Robotic Exploration of Extreme Environments

www.robex-allianz.de

Investigating the Basis of the Marine Food Chain with an AUV

T. Wulff, S. Lehmenhecker, J. Hagemann, E. Bauerfeind

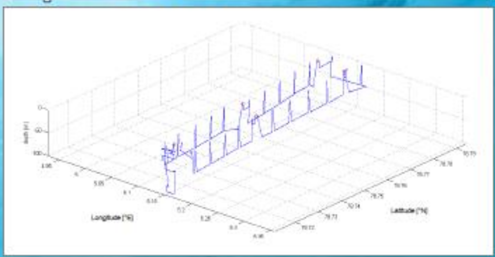
Alfred Wegener Institute Helmholtz Center for Polar and Marine Research

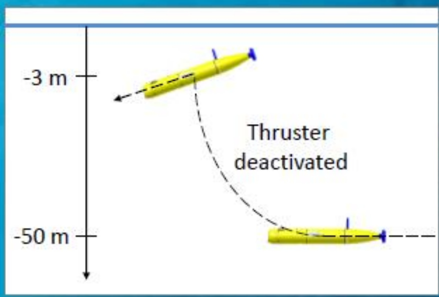
1. Vehicle

Parameters / Instrumentation:

- Conductivity
- Temperature
- Pressure
- Nitrate
- Photosynthetically Active Radiation
- Carbon Dioxide
- Fluorescence (Chlorophyll a)
- Fluorescence (CDOM)
- Dissolved Oxygen
- Sample Collector

2. Operation



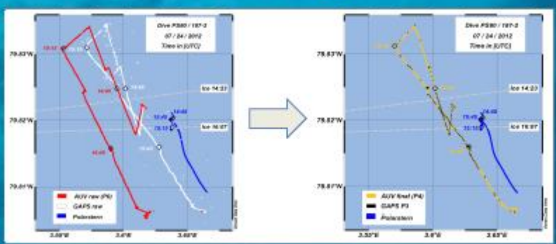


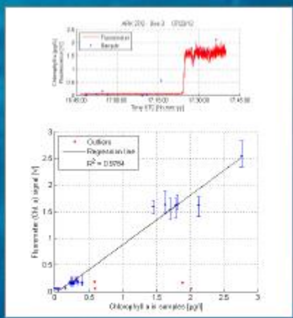
Float Maneuver:

Thruster deactivated
- -> Vehicle ascends slowly
- -> Little disturbance of surface water stratification
- -> High resolution vertical profile

Repeated Floats for 3D investigation

3. Data processing





Data Correction (left image):

Acoustic vehicle tracking
- -> Correction of navigation errors
- -> Resilient georeferencing

Sensor Calibration (right image):

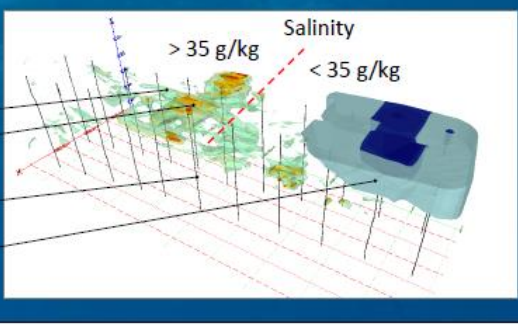
Collecting water samples during the dive
- -> In-situ calibration of sensor data
- -> Quantitative Chlorophyll a data

4. Results

Chlorophyll a concentration:
- > 2.5 µg/l
- > 4.0 µg/l

Ascend during Float maneuver

10 m thick melt water layer (salinity < 34.5 g/kg)



Dive in Arctic Marginal Ice Zone:

- -> Chlorophyll a as tracer for phytoplankton and marine primary production
- -> Almost synoptic, volumetric investigation of phytoplankton standing stock
- -> "Patchy" distribution of phytoplankton along ice edge

ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG · Deutsches Zentrum für Luft- und Raumfahrt DLR · GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel · marum · JACOBS UNIVERSITY · TECHNISCHE UNIVERSITÄT DRESDEN · Technische Universität Kaiserslautern · Technische Universität München · Technische Universität Berlin · Deutsches Forschungszentrum für Künstliche Intelligenz GmbH · Universität Bremen

HGF Alliance ROBEX
Robotic Exploration of Extreme Environments

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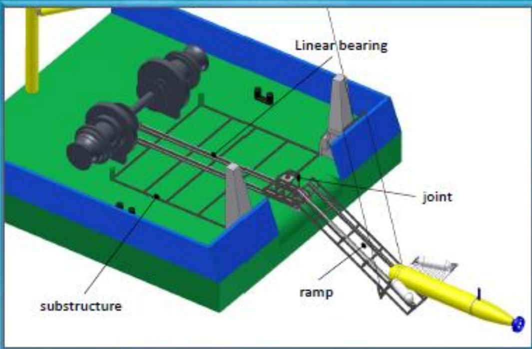
Allianz

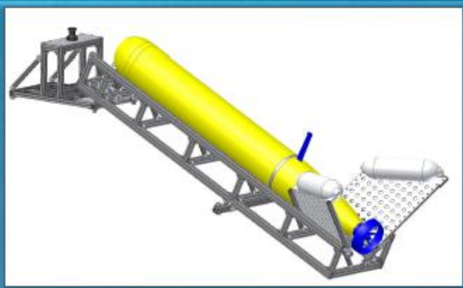
Design of a Launch and Recovery System for an AUV, developed for the research vessel FK Uthörn

J. Hagemann, T. Wulff
Alfred Wegener Institute Helmholtz Center for Polar and Marine Research



Design

- The Launch and Recovery System (ABS = German: Aussetz- und Bergesystem) is attached to the working deck by a substructure.
- On the substructure the rails of the linear bearing are installed.
- The slide with the joint connects the deck equipment with the ramp.
- The ramp is equipped with wheels to launch and recover the AUV.
- For an easier recovery of the vehicle there is a guiding plates at the end of the ramp. When deployed, the ramp floats on the water and thus performs the same, wave driven motion as the AUV.



Launch & Recovery

In order to minimize unpredictable movements, ship will turn bow towards prevailing wave direction and will keep slow forward movement.

Launch
- Extending the ramp and lowering it into the water.
- Smoothly slip the vehicle into the water and release the line.

Recovery
- Catch the nose line and pull the vehicle up the ramp.
- Lifting up the ramp and fix it in transport configuration.

Material

The ABS intended to be a simple, efficient and cost-effective construction, which can be used in the marine environment (risk of corrosion). The main materials used are:
- Bosch Rexroth Aluminum Framing – basic structure
- Igus DryLin® W – linear bearing
- Stainless steel – joint and high loaded elements

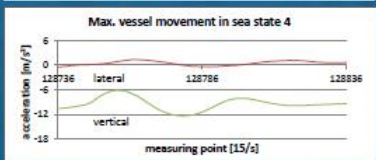
Vehicle

Autonomous Underwater Vehicle (AUV)

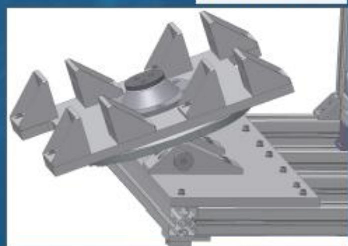
- Bluefin-21 "Paul".
- Vehicle details:
  - Diameter: 53 cm (21")
  - Length: 430 cm
  - Weight(Dry): 450 kg
- Modular structure (4 modules).
- Vehicle´s interior is entirely flooded.
- Residual buoyancy is app. 40 N.
- The vehicle can be pulled up on the central Lift-Point (vertical) and on the front Lift-Point (max. 45°).

The Joint

- Connecting joint between slide and ramp has two degrees of freedom (DOF):
  - Hinge joint
  - Pivot joint
- Two DOFs are necessary due to the complex vessel movement.



Interface



Platform

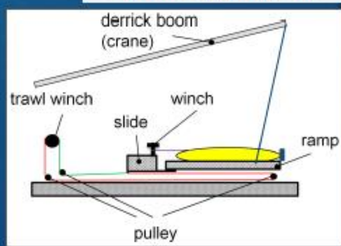
FK Uthörn

- Small research vessel Uthörn, built in 1982
- The area of operations is the German Bight.
- Vessel details:
  - Length: 30 m
  - Beam: 8.3 m
  - Draught: 2.5 m
  - Speed: 10 kn
- The vessel is equipped with a derrick boom and a trawl winch.
- Safe work on deck up to sea state 4.

Mechanical Motion

- Ship equipment such as derrick boom and trawl winch are sufficient to enable ABS operations.
- The movement of the slide is controlled by the trawl winch, which is connected with the slide by ropes.
- The ramp can be moved up and down by the derrick.
- For launch and recovery operations, trawl winch and derrick have to work simultaneously.
- To pull the AUV out of the water, a winch mounted on the slide is used.

Operating Mode



For further information please visit our Web-Site: http://www.awi-bremerhaven.de/Research/ProjectGroups/DeepSea/index.html
or contact: Jonas.Hagemann@awi.de, Phone: +49 471 4831-2045

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Fakultät Bauingenieurwesen, Institut für Massivbau

BETON – BAUSTOFF FÜR MOND UND TIEFSEE

Die Rückkehr der bemannten Raumfahrt zum Mond ist nur eine Frage der Zeit. Neben China, Indien, Russland und Japan plant auch die NASA bis 2024 ihre Rückkehr zum Mond und die Errichtung einer permanenten lunaren Forschungsstation. Ebenso wie der Mond ist die Tiefsee ein weitgehend unerforschtes Gebiet, in dem ebenfalls extreme Umgebungsbedingungen herrschen. Wie Beton zur Errichtung von Forschungsstationen oder bei der Erkundung der Tiefsee verwendet werden kann, ist Inhalt der Forschung am Institut f. Massivbau im Rahmen von ROBEX (Robotic Exploration of Extreme Environments).

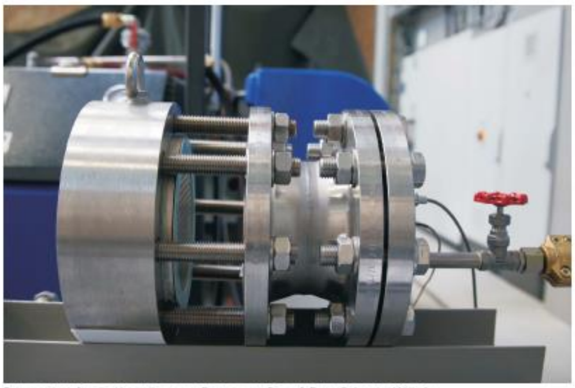
Lunarer Beton

Die lunare Umgebung stellt große Herausforderungen an das Material für den Bau einer Basisstation. Aufgrund der dünnen Atmosphäre gibt es Temperaturschwankungen von 280 K auf der Mondoberfläche, eine hohe Strahlungsintensität, ein hohes Vakuum sowie den dauerhaften Beschuss durch Meteoriten und Mikrometeoriten mit Geschwindigkeiten von bis zu 70 km/s.

Regolithsimulat, Foto: Silke Scheerer

Nach vorerst temporären Konstruktionen aus leichten Materialien wie z.B. Carbon ist die Errichtung eines massiven Habitats unumgänglich. Da der Materialtransport zum Mond begrenzt und kostenintensiv ist, wurden Möglichkeiten untersucht, einen mineralischen Baustoff aus den vorhandenen lunaren Ressourcen herzustellen. Dabei stellte sich heraus, dass alle notwendigen Materialien für die Betonherstellung – Zuschlag, Zement und Wasser – bereits auf dem Mond in ausreichender Menge vorhanden sind.

Die Eignung von Mondregolith als Zuschlag im Beton konnte bereits 1986 von T. D. Lin demonstriert werden, der einen Beton aus 40 g lunaren Regoliths der Apollo-16-Proben herstellte. Auch die Gewinnung von Zement aus lunarem Gestein konnte z. B. durch Horiguchi ebenfalls bereits bewiesen werden. Die Frage nach Wasser auf dem Mond beschäftigte die Forscher Jahrzehnte lang. Das LCROSS- Impakt-Experiment gab erstmals Aufschluss, bestätigte das Vorhandensein von Wasser in Form von Eis an den lunaren Polen und macht somit die Herstellung eines Betons auf dem potentiell Mond möglich.



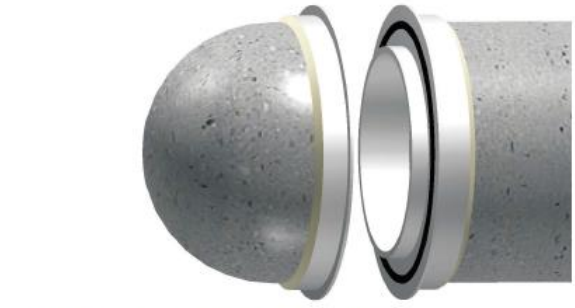
Betonreaktor für die Herstellung von Beton unter Dampf, Foto: Sebastian Wilhelm

Die wissenschaftliche Herausforderung ist es nun, ein Betonherstellungsverfahren zu entwickeln, welches unter Vakuumbedingungen möglich ist. Grundlage der Forschungsarbeit sind Ergebnisse der Dry-Mix/Steam-Injection Methode (DMSI), welche bereits 1990 von T. D. Lin entwickelt wurde. Anders als bei der konventionellen Herstellung von Beton im Nassmischverfahren erhärtet ein Trockengemisch aus Zement und Zuschlag unter Druck und hoher Temperatur. Der verwendete Sattdampf bietet gegenüber dem Nassmischverfahren eine Vielzahl an Vorteilen wie z. B. geringere Wasser-Zement-Verhältnisse, keine Probleme mit der Verarbeitbarkeit bei geringen W/Z-Werten sowie kürzere Hydratationszeit und höhere Festigkeit gegenüber Normalbeton.

Projekttitel:	ROBEX – Robotische Exploration unter Extrembedingungen
Förderer:	Helmholtz-Gemeinschaft
Förderungszeitraum:	10.2012 – 09.2017
Projektleiter:	Prof. Dr.-Ing. Dr.-Ing. E.h. Manfred Curbach
Projektbearbeiter:	Dipl.-Ing. Sebastian Wilhelm

Hochleistungsbeton für Druckgehäuse der Tiefseemeeresforschung

Die Tiefseeforschung ist ein wesentlicher Bestandteil der Meeresforschung. Dabei spielen neben ökologischen Aspekten auch zunehmend wirtschaftliche Interessen wie die Suche nach alternativen Energieressourcen (z. B. Methanhydrat) eine bedeutende Rolle. Für den Aufbau von temporären und permanenten Forschungsstationen unter Wasser werden aufgrund der extrem korrosiven Umgebung bisher vorwiegend teure Materialien wie Titan und Aluminium verwendet.



Design eines Druckgehäuses aus UHPC, Visualisierung: Sebastian Wilhelm

Untersucht werden soll deshalb die Eignung von hochfestem Beton für Unterwasser-Druckbehälter, um eine kostengünstige Alternative zu derzeitig verwendeten Titanbehältern zu schaffen. Dabei müssen eine geeignete Betonzusammensetzung und Bewehrung gefunden und die Auswirkungen der marinen Umweltbedingungen hinsichtlich Korrosion (Chloride, Sulfate etc.) untersucht werden. Für die Herstellung des dünnwandigen Deckels eines Prototyps von nur 10 mm Dicke wurde eine Schalung aus Polyurethan gefertigt, um die gewünschte Oberflächen-beschaffenheit und Maßhaltigkeit zu gewährleisten.

Schalform aus Polyurethan, Foto: Sebastian Wilhelm

Ziel ist die Optimierung der Konstruktion entsprechend der Belastung mittels der Finiten-Elemente-Methode (FEM). Dabei soll bereits bei der Berechnung die erhöhte Festigkeit von Beton unter mehraxialer Beanspruchung berücksichtigt werden. Ein weiterer Schwerpunkt der Arbeit liegt in dem Entwurf eines Dichtungssystems für angestrebte Tiefen bis 6000 m. Abschließend soll ein Prototyp angefertigt und in einer Druckkammer auf Belastbarkeit und Dichtheit getestet werden, bevor ein weiteres Druckgehäuse in der maritimen Umgebung ausgesetzt werden soll. Dabei wird das Institut für Massivbau von der Jacobs Universität Bremen und dem Alfred-Wegener-Institut (AWI) unterstützt.

Deckelschale aus UHPC (links) und FEM-Modell des Druckgehäuses (rechts), Sebastian Wilhelm

Analysis of modularity and product platforming principles for lunar infrastructures

1 Motivation

To reduce the cost of future lunar exploration infrastructures we need to develop architectures that can be reused thus providing savings in development cost and time!

Fig. 1: Representation of the 'Iron Triangle' [1]

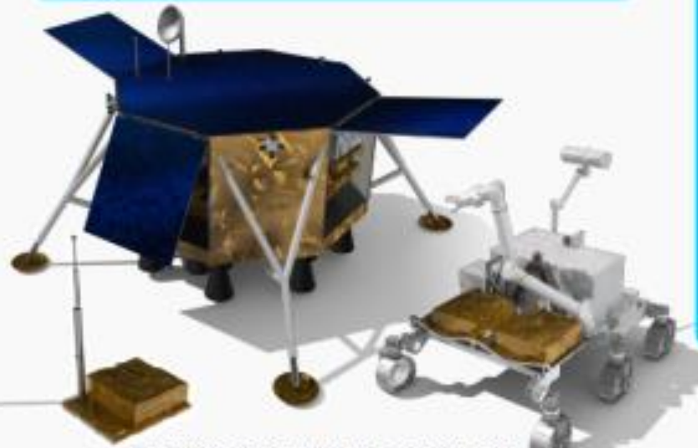


Fig. 2: A lunar lander, rover and a scientific module (self-sustainable, to be placed on the lunar surface) incorporating the principle of bus-modularity [2]

2 Background

Every infrastructural system can be formally represented ... describing its behaviour and structure ...via the mapping of functionality to hardware and software components

•

In a Model-Based Systems Engineering (MBSE) approach this information is stored in the system model.

•

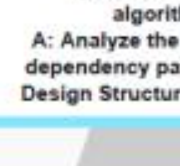
Systematic application of platfoming and modularity methods requires looking into the structural and performance aspects of the system dependently.

•

In order to investigate these methods systematically they need to be applied in the MBSE environment.

Q: Why should we to develop common systems for different applications?
A: Realize [6]
- required flexibility in use
- add-on capability
- adaptations to environments (during the systems life and across generations)

Fig. 3: Example for a DSM



Q: How to develop common systems for different use?
A: Use product platforming methods. Product families with a certain degree of commonality are based on either modular or scalable product platforms.

Q: How to capture aspects such as Modularity, Commonality and Variety of a system or among two systems objectically and algorithmically?
A: Analyze the system elements dependency patterns using e.g. a Design Structure Matrix (DSM) [3].

Q: How to identify the best degree of commonality and variety of the product platform?
A: Apply product family evaluation methods (e.g. the Market Sementation Grid (MSG [4]) and Product Family Evaluation Graph (PFEG [5])) based on lander requirements analysis and functional breakdown.


Fig. 4: Example for a MSG [4]

Q: How to identify the best type and degree of modularity?

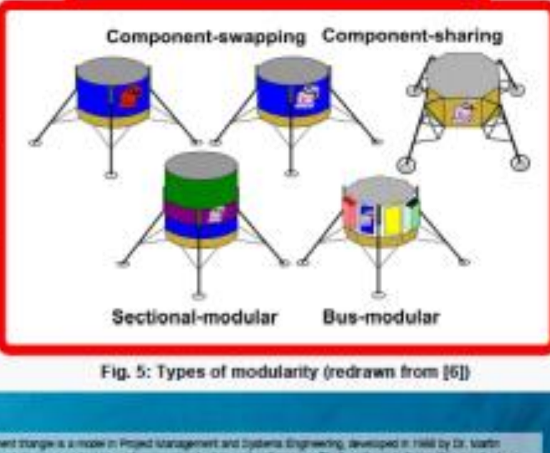


Fig. 5: Types of modularity (redrawn from [6])

This poster has been designed for the 4th Community Workshop within the ROBEX Helmholtz Alliance, held at Dresden from March 17th to 19th 2014.

Author Information:
Caroline Lange
German Aerospace Center (DLR) Institute of Space Systems
Robert-Hooke-Str. 7
28359 Bremen
Germany
Email: Caroline.Lange@dlr.de
Telephone: +4942124420115 9

[1] The Iron Triangle or Project Management triangle is a model in Project Management and Systems Engineering, developed in 1969 by Dr. Martin Barnes, that describes the interrelationships between a project (or systems) cost, schedule and performance. The hypothesis is that putting emphasis on any two of the three aspects will ultimately effect the last aspect. In other words "Fast, cheap or good: pick any two" (old saying, source unclear). Thus, if we want to reduce the time to flight and cost for future (e.g. lunar) exploration systems, while keeping the overall performance, we have to introduce new concepts and methods, such as product family and modularity concepts.
[2] The lunar lander as designed for the ROBEX ASN Scenario during the CE-Study in Aug 2013 @DLR Bremen. Described in the Concurrent Engineering Study Report: DLR-RY-CE-R012-2013-3 "Feasibility Study ROBEX ASN - Active Seismic Network"
[3] The term Design Structure Matrix has been coined by D. Steward in 1981. An DSM is a compact visual representation of a system's structure in matrix shape. Ref: D. V. Steward: The Design Structure System: A Method for Managing the Design of Complex Systems. In: IEEE Transactions on Engineering Management. 28(3), 1981, S. 71-74.
[4] The MSG is a method used for product differentiation in different market segments, first introduced by Meyer and Lehnerd in 1997. Ref.: Meyer, M.H. and Lehnerd, A.P. (1997) The Power of Product Platforms: Building Value and Cost Leadership, Free Press.
[5] The PFEG is a method to perform the commonality/variety tradeoff of a product family, as described in Ye, X. et al. (2007). A Quantitative Representation of the Tradeoff between Product Commonality and Variety in a Product Family Design. ICED '07/409

Transportation Systems for Modular Robotic Moon Infrastructure

Etienne Dumont
DLR - German Aerospace Center, Institute of Space Systems, Bremen

Depiction of possible Lunar Base (Credits NASA)

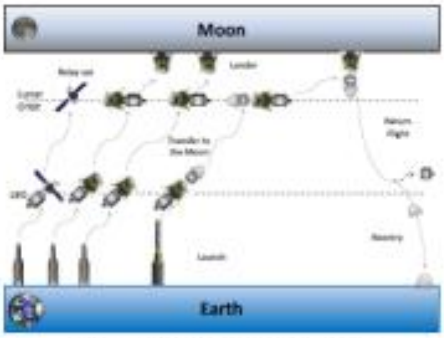
Motivation

- **Design of a transportation system and strategy** for modular robotic Moon infrastructure:
  - Experiment and research: geophysics, radio-astronomy, solar system observations, influence of cosmic environment, etc
- Re-supply capability for long term mission, experiment modification
- Return capability (sample return)
- Pave the way for future manned missions
  - Test of techniques and technologies (power supply, pressurized module, ISRU), landing site and habitat preparation

Missions and roadmap

A large range of missions can be performed with modular robotic infrastructure. Cooperation and synergies between missions should be optimized with an adapted **manifest roadmap** which influences:

- Flexibility, growth potential: incremental growth with arrival of new modules
- Success probability vs complexity
- Mission cost and sustainability



Manifest roadmap for a Moon mission

Saturn V launch (Credits NASA)

Launcher and transfer module

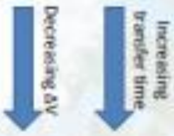
For pathfinder and rare missions, current launch vehicles are sufficient to perform transfer from Earth to the Moon. For more regular missions and larger experiments **new launchers** and **transfer modules** could be an asset:

- Increase in range of feasible missions (transfer duration, sample return)
- Larger payload volume capacity and payload performance reduces mission complexity
- Drastic launch cost reduction with larger launchers (recurring cost optimization)

Trajectory and rendezvous strategy

Depending on the mission (payload, final destination, need of return capability, allowed transfer duration) **several trajectories** and **rendez-vous strategies** can be considered:

- Direct injection
- TLI after LEO or GTO
- WSB (Weak Stability Boundary close to L1 Sun/Earth)



Typical Moon Mission with return (Credits NASA, J. Frassanito)

Effects of Ejected Lunar Soil Particles on Lunar Infrastructures

Author: Dipl.-Ing. Christian Bühler
Technische Universität München, Lehrstuhl für Raumfahrttechnik,
Boltzmannstr. 15, 85478 München

Introduction

Lunar bases need multiple start and landing operations for resupply or sample return during their lifecycle. Landings and take-offs would most likely take place in the vicinity of the base, such as the landing of Apollo 12, which was close to the earlier landed Surveyor 3 probe. Its exhaust jet stirred the lunar soil and sandblasted the surface of Surveyor 3, which lead to heavy erosion. This shows that close landing operation may cause serious damage to infrastructure elements. But also soil particles with smaller velocities, e.g. ejected by rover movement, can possibly endanger lunar surface infrastructure. So it is necessary to carefully examine the different ***effects of ejected lunar soil particles on lunar infrastructures.***

Apollo 12 astronaut inspecting the Surveyor 3 probe[1]

[1] http://grin.hq.nasa.gov/ABSTRACTS/GPN-2000-001318.html

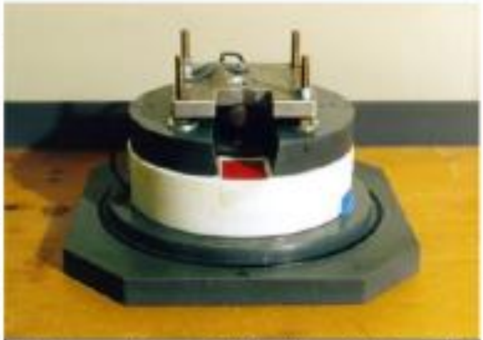
Methods

Experimental Analysis of High-Velocity Dust Impacts

- Flat coil accelerator
- Velocities up to 500 m/s
- Under high vacuum conditions
- Impact particles: lunar regolith simulant (JSC-1A), ice mixed with JSC-1A
- Impact characterisation via microscope: single or multiple impacts
- Measuring the variation of surface roughness

Analysis of Wear Problems

- Gear test bench for studies of wear caused by lunar regolith
- Examination of wear-resistant materials for planetary (lunar) applications

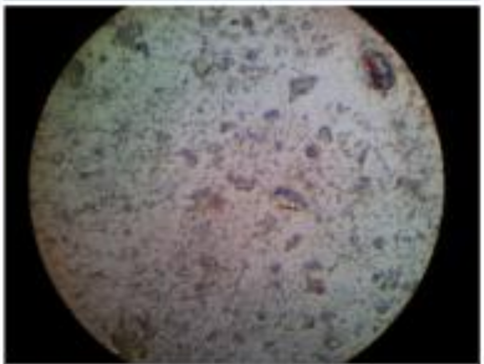


Flat coil accelerator at TUM Institute of Astronautics

Expected results (2)

High-Velocity Impacts

- Determination of damage characteristics for different target- and projectile materials
- Determination of damage characteristics for varying target geometries
- Investigation of possible mitigation technologies for high-velocity impacts
- Determination of "no damage" velocities for different target/ particle materials and target geometries
- Estimation of safe zones for landing vehicles
- Restrictions for potential base sites with respect to landing operations



Lunar dust particle impacts on aluminum (40x image magnification); Velocity of impacting particles is about 130 m/s;

Objectives

- Determine different sources of lunar dust ejection with corresponding particle velocities
- Examine the effects of high-velocity dust particle impacts on technical surfaces e.g. MLI, glass, seals
- Analyse wear problems due to low-velocity dust trapped in gear boxes

Expected Results (1)

Wear Problems

- Long-term measurements of wear caused by lunar regolith
- Characterisation of wear effects, dependent on dust type and environmental conditions
- Suggestion of possible gear materials that can withstand lunar conditions especially the dust environment

Current Work

Preliminary impact experiments were carried out at rather low velocities (about 130 m/s). Despite these velocities were only about one fourth of the actual impact speed serious damages occurred on metallic surfaces. Further investigation of dust impacts is ongoing. Besides a wear test rig will be developed for further study of possible wear problems.

Dipl.-Ing. Christian Bühler
Technische Universität München
Boltzmannstr. 15, 85748 Garching

Phone +49 (0)89 289 16007
Fax +49 (0)89 289 16004

email c.buehler@tum.de
web www.lrt.mw.tum.de

Characterisation of the Meteoroid Environment of the Moon from Ground-based Telescopic Observations of Impact Flashes

A. Margonis [1] , R. Luther [1,2], J. Oberst [1,3], F. Sohl [3], J. Flohrer[3]
[1] Technische Universität Berlin, Institut für Geodäsie und Geoinformationstechnik
[2] Humboldt-Universität zu Berlin, Institut für Physik
[3] Deutsches Zentrum für Luft- und Raumfahrt, Institut für Planetenforschung, Berlin-Adlershof

Introduction

The Moon's surface is constanlty exposed to dust particles, called meteoroids, ranging in size from a few milimeters up to tens of meters. Most of these particles are fragments from comets and are produced during the perihelion passage of the comet. At that time the surface of the comet is heated up by the Sun and frozen material is turned into gas. As a result, dust particles are ejected from the surface of the comet moving along orbits similar to their parent comet. Other particles have their origin in collision impacts between larger objects like asteroids. Unlike Earth, where most of these particles burn up in the atmosphere, Moon has no atmosphere which allows meteroids to hit directly its surface at high velocities. The energy of such impacts give birth to several phenomena from short-lived flashes and propagation of seismic waves to formation of impact craters on the lunar surface. Reports of temporal variations of the appearance of the Moon date back to 12th century. The first scientifically confirmed lunar meteoritic impact flash observed from Earth was recorded in 1999 during the Leonids meteor shower.

Figure 1. Comet Hartley 2 as seen by Deep Impact spacecraft during its close encounter. The image shows the comet nucleus outgassing jets from its surface into space (left). Comet ISON during its perihelion passage in November 2013.

Scientific Questions

• What is the meteoroid flux of meter-sized objects in the Earth-Moon system today?

• Are there any temporal and/or spatial variations of meteoroid impacts?

• Can the current models of crater production rates be confirmed with observations of impact flashes?

• Is there any relation between lunar impacts and changes in the teneous atmosphere of the Moon?

• How do the impact flash observations constrain models describing the crater formation processes and the crust of the Moon?

Observations Technique

• Use of sensitive video cameras with a hight frame rate attached to telescopes for monitoring the dark hemisphere of the Moon for impact flashes.

• Adaption of the focal length of the telescope by using either Barlow lenses or focal reducers enables the adjustment of the field of view and herewith the lunar surface that can be observed with a camera. A relatively large field of view will include stars in the image, allowing the photometric calibration of the flashes.

• Observations are being held when the Moon is between 10% and 50% illuminated at both lunar phases (waxing and waning). The lower limit ensures sufficient observing time while the higher limit avoids straylight coming from the sunlit portion of the Moon (see Fig. 2).

• The data are analysed for impact flash detections. Estimating the brightness of the flash and knowing the impact velocity, the physical properties of the impactor can be calculated. Furthermore, the event can be confirmed by searching for fresh craters within the area of the impact flash.

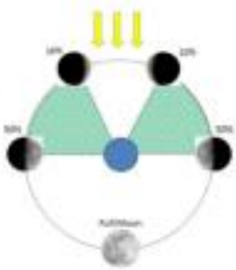


Figure 2. Graph showing the position of the Moon along its orbit and its apparent view from Earth. The shaded patern (green) rerpesents the phases of the Moon at which observations are desired.

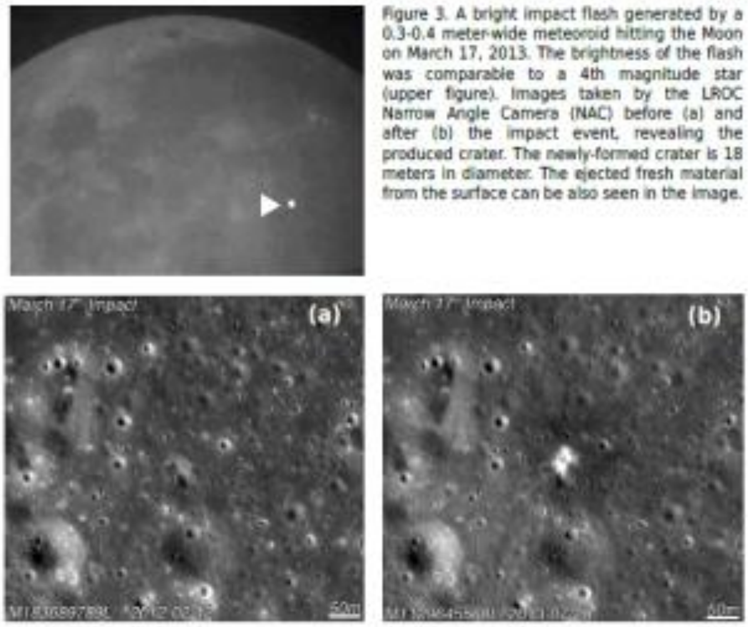


Figure 3. A bright impact flash generated by a 0.3-0.4 meter-wide meteoroid hitting the Moon on March 17, 2013. The brightness of the flash was comparable to a 4th magnitude star (upper figure). Images taken by the LROC Narrow Angle Camera (NAC) before (a) and after (b) the impact event, revealing the produced crater. The newly-formed crater is 18 meters in diameter. The ejected fresh material from the surface can be also seen in the image.

Liebenhof Observatory

For our observations we use the facilities in Liebenhof observatory located 40 km east of Berlin near Buchow. The observatory is equipped with a 20cm f/7 TMB Apo Refractor and a f/4 Lichtenknecker of same size. Both telescopes are mounted on a high quality GM4000 equatorial mount that can be controlled remotely. Currently, we use two cameras, a DFK 21AU04 and the SPOSH camera head. Both have different characteristics which allows us to evaluate different aspects of them.

Figure 4. The TMB-Refractor and the Lichtenknecker telescopes shown inside the dome in Liebenhof (left). A composite image of the illuminated lunar surface produced by several hundred stacked single frames on 16.08.2013 taken with the TMB refractor and the DFK camera.

Conclusions

We are going to study the meter-sized meteoroid population in the Earth-Moon system by observing the dark hemisphere of the Moon for impact flashes. The observed meteoroid flux will shed additional light on the previous theoretical and analytical studies of flux asymmetries and temporal variations. Future seismic networks on the Moon, similar to the proposed MOVE network, will benefit from impact flash observations, which will provide the acquired ground-truth data for analysing the seismic data and re-evaluate lunar interior models.

Aknowledgement

This research has been supported by the Helmholtz Association through the research alliance "Robotic Exploration of Extreme Environments".

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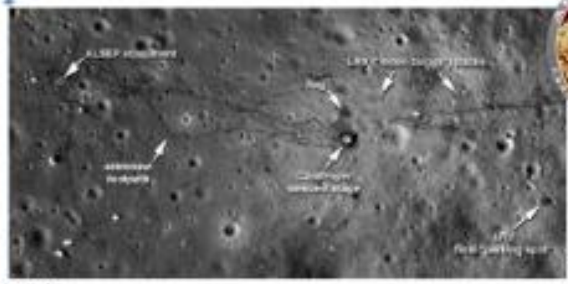
ROBEX Allianz

The ROBEX – Active Seismic Network

Alexandra Czeluschke[1], Martin Knapmeyer[1], Jürgen Oberst[1,2], Isabel Haase[2]

(1) German Aerospace Center (DLR), Institute Of Planetary Research, Berlin, Germany; (2) Institute for Geodesy and Geoinformation Sciences, Technical University Berlin, Germany

1. Historical Facts



Picture 1: Apollo 17 landing site taken by LRO in its lower orbit, with 25 cm per pixel. (NASA/Goddard/ASU)

Apollo 17

- Lunar Seismic Profiling Experiment (LSPE) represents the largest active seismic experiment to explore the subsurface of the Moon
- Sources: 8 explosive packages (EP), amount of explosive material varying from 53g to 2722g
- Receivers: 4 geophones in Y-shaped array

2. Lunar Reconnaissance Orbiter and new Coordinates

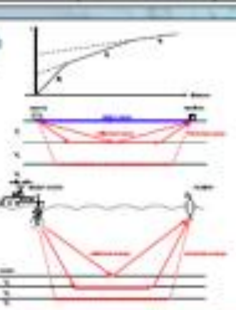
- LRO launched on June 18, 2009
- high-resolution mapping of the lunar surface from orbit (max. resolution 50cm/pixel)
- allowed detailed mapping of the Apollo landing sites and reconstruction of seismic network geometry
- hi-res maps and re-examination of surface photographies taken by astronauts were combined to obtain geometrically accurate lunar-fixed Mean-Earth/Polar Axis-coordinates of Apollo sites and equipment
- significant point deflections (1m up to 10m) between previously published coordinates and new LROC supported values found

Picture 2: „Locator" image of seismic charge EP-6 taken from the drivers seat out to the Lunar Roving Vehicle's front. The yellow lines depict image rows of identical directions. (Hasselblad frame AS17-145-22184; NASA)

Table 1: Example for significant point deflections (Data: Isabel Haase)

Charge	Geophone	Distance Cooper et al. 1975	Distance TUB/LROC, 2015	Point Deflection
EP-6	1	170m	169.8m	-0.2m
	2	101m	96.2m	-5.8m
	3	122m	112.2m	-9.8m
	4	112m	101.6m	-10.4m

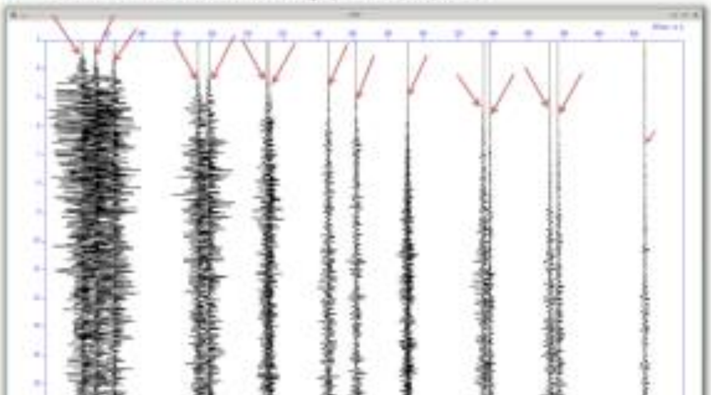
3. Seismic Refraction



- geophysical principle based on Snell's Law
- hammers, drop weights, explosions, vibrators, airguns or other sources are used to generate artificial seismic waves
- seismic refraction traverses are performed using seismographs, geophones or hydrophones in an array
- method uses the refraction of seismic waves on geologic layers and rock/soil units to determine subsurface structure
- analysis of wave travel time curves and intercept times to get subsurface velocity models
- different configurations regarding to source and receiver position possible: land-land, land-marine, marine-land, land-land

4.

Plot 1: Seismic signals of detonations of Explosive Packages 2,3,4 and 8 recorded by the four geophones of the Apollo 17 LSPE array plotted according to their offsets (for better visibility of single traces only the detonations of the four EPs closest to the geophone array are plotted)



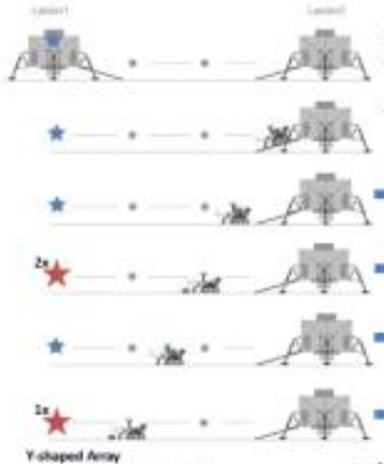
Acknowledgements

This research is supported by the Helmholtz Alliance ROBEX (HA-304).

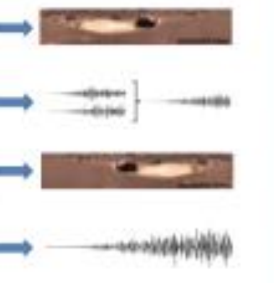
5. Concurrent Engineering Study for a First Mission Outline

conducted at DLR Concurrent Engineering Facility (DLR Institute of Space Systems, Bremen)

Seismic Profile



- Precision Landing: distance of 10km between Lander1 and Lander2
- Lander1 carrying a repeatable source (blue star) and additional seismometers
- Lander2 carrying the rover with one seismometer



Y-shaped Array

- after profile completion rover deploys a Y-shaped array of four seismometers (green dots)
- for passive listening mode, impact registration, and event location

6. Traceability Matrix for the ROBEX Mission

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

7. What shall be done for the PhD-Thesis?

- re-examination of Apollo 17 LSPE data with respect to new LRO coordinates
- design of a new seismic experiment concept to explore the subsurface of the Moon
- design of a new seismic experiment concept that can be conducted autonomously by robotic rovers on the Moon
- collaboration with different external partners, i.e. for applicability of experiments on terrestrial analog sites
- in preparation for the ROBEX demo mission: Design, deployment and operation of a small seismic network near DLR facility in Weilheim where a thermal drilling project will be conducted, afterwards evaluation of received drilling data
- work on questions: network layout, on-board data-processing, communication between different autonomous components
- evaluation of final ROBEX demo mission data

Contact

Dipl.-Geophys. Alexandra Czeluschke

alexandra.czeluschke@dlr.de | www.DLR.de

German Aerospace Center | Institute for Planetary Research | Planetary Physics | Rutherfordstr. 2 | 12489 Berlin | Germany

DLR

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DLR

Untersuchung der Energiegewinnung aus lokal vorhandenen Temperaturgradienten mit Hilfe der Phönixbox

Motivation

Die Versorgung eines Außenpostens oder einer Infrastruktur mit Energie ist essentialer Stützpfeiler der Exploration von Planten und unserer Tiefsee. Hierbei ist es wichtig eine Versorgung zur gewährleisten, die autark die vor Ort gegeben Ressourcen als Energiequelle nutzt. Eine Herausforderung ist die Versorgung auch in der Dunkelheit. Um eine autarke und dazu noch umweltfreundliche Energieversorgung zu gewährleisten, werden die lokal gegebenen Temperaturunterschiede, die bei Schwarzen Rauchern und auf dem Mond vorhanden sind, zur Energieerzeugung verwendet.

Stand der Technik

Durch die Nutzung der Thermoelektrizität, dessen Ursprung auf den Physiker Seebeck (1821) zurückgeht, ist es möglich, einen Temperaturunterschied in elektrische Energie umzuwandeln. Werden zwei verschiedene Metalle verbunden und die beiden Berührungspunkte unterschiedlichen Temperaturen ausgesetzt, entsteht ein Thermostrom. Dieser kann durch einen angeschlossenen Verbraucher genutzt werden.

Zurzeit wird die Thermoelektrik als Energiegewinnung u. a. in folgenden Missionen / Anwendungen verwendet.

Raumfahrt:

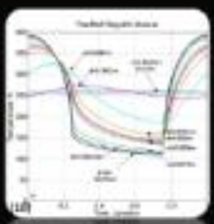
- Cassini Huygens (1997) nutzt eine Radionuklidbatterie
- Curiosity (2011) nutzt ebenfalls eine Radionuklidbatterie

Terrestrisch:

- Luftfahrtindustrie nutzt die Abgasabwärme
- Automobilindustrie nutzt die Abgasabwärme
- Energy Harvesting nutzt die Abwärme elektrischer Bauteile

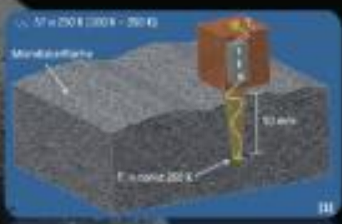
[3]

Raumfahrtanwendung



Für die Raumfahrt ergeben sich durch die Nutzung der Phönixbox neue Möglichkeiten Energie zu erzeugen. Die Phönixbox nutzt die natürlich gegebenen lokalen Temperaturgradienten und wandelt diese mithilfe der Thermoelektrik in elektrische Energie um. Die Energieversorgung kann somit unabhängig von externen Treibstoffen und sogar dem Tag/Nacht Zyklus realisiert werden.

- Ausnutzung der Temperaturgradienten
  - Oberfläche und Untergrund ($\Delta T \sim 250$ K), siehe Grafik links
  - Oberfläche und permanent beschatteter Krater ($\Delta T \sim 300$ K)
  - Sonne- und Schattenseite des Raumfahrzeuges ($\Delta T \sim 120$ K)
- Erste Ergebnisse
  - Es ist möglich bis zu 20W in elektrische Leistung umzuwandeln
  - Die Leistungsdichte liegt bei ungefähr 1,5 W/cm²

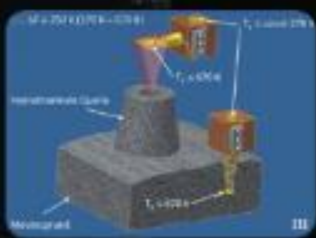


[1,2]

Tiefseeanwendung

Für die Tiefsee wird durch die Phönixbox eine Energieversorgung vor Ort realisiert, die bis dato noch nicht möglich war. Hierzu werden die Temperaturgradienten, die bei Schwarzen Rauchern auftreten verwendet. Es muss jedoch noch geprüft werden welchen Einfluss die Installation einer Phönixbox auf die Umwelt hat.

- Ausnutzung der Temperaturgradienten
  - Austrittsströmung des Schwarzen Rauchers und Umgebungsströmung ($\Delta T \sim 250$ K)
  - Untergrund und Umgebungsströmung ($\Delta T \sim 250$ K)
- Erste Ergebnisse
  - Durch die Konvektion ist sichergestellt, dass die Temperatur am Thermokontakt (T_1)der Umgebungsströmung nahezu konstant bleibt, die Strömung des Schwarzen Rauchers verändert jedoch die Temperatur am Thermokontakt (T_2)



[1]

Ausblick

Die ersten Berechnungen haben gezeigt, dass eine Anwendung der Phönixbox auf dem Mond möglich ist. Die Verwendung für die Tiefsee wird untersucht. Hier begünstigt die Konvektion des Schwarzen Rauchers die Temperatur der heißen Seite. Diese Strömung sorgt für eine nahezu konstante Temperatur, dadurch kann durch die Phönixbox konstant Energie umgewandelt werden. Weiterführende Simulationen werden für beide Umweltumgebungen die Anwendbarkeit untermauern und den möglichen Energieertrag berechnen. Diese Simulationen sollen durch den Aufbau von Demonstratoren für die entsprechenden Temperaturbereiche validiert werden. Hierbei sei angemerkt, dass die Effizienz der Phönixbox von der Effizienz der thermoelektrischen Generatoren abhängig ist. Diese wird durch aktuelle Forschungen verschiedener Industriebereiche ebenfalls vorangetrieben.

Ist die Validierung erfolgreich, wird die Energieerzeugung unter Umgebungsbedingungen getestet. Damit wird gezeigt, dass es möglich ist, die lokalen Temperaturgradienten zur Energieversorgung zu nutzen und dass es eine umweltfreundliche Alternative darstellen kann.

Roland Rosta
Deutsche Zentrum für Luft- und Raumfahrt
Institut für Raumfahrtsysteme
Robert-Hooke-Str. 7
28359 Bremen

E-Mail: roland.rosta@dlr.de
Tel.: 0421/244201128

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Smart Power Grid Topology for Space Applications

Georgios Tsakyridis

Georgios.Tsakyridis@dlr.de

DLR – German Aerospace Centre
Institute of Space Systems
Dep. Exploration Systems
Robert-Hooke-Str. 7
28359, Bremen, DE

2nd ROBEX Training Workshop, 19/20th March 2014, Dresden, DE

Introduction

Within the Helmholtz alliance's "Robotic Exploration of Extreme Environments (ROBEX)", a significant effort is being put towards exploring synergies between two up to now unrelated research fields: deep sea exploration and lunar exploration.

Motivation and Background

The deployment of a possible geophysical study network, within ROBEX, is studied. Scientific requirements for geophysical and geodetic investigation of the Moon would dictate landing sites and system architecture for the overall mission. The conceptual design of a power generation, storage, transmission and management system capable of sustain such activities is studied.

Modular Lunar Infrastructure

- **Modular Lunar Infrastructure:** infrastructure used to accomplish complex tasks in the extreme and highly uncooperative and difficult-to-access Lunar environment. The baseline of the infrastructure would compose:
  - 2 lunar landers
  - 1 cargo rover and 1 scientific rover
  - Communication terminals
  - Remote sensor units

Fig.1. An example of a modular Lunar outpost as presented in the CEF study in DLR Bremen.

Smart Grid

- **Smart Grid:** an evolved grid system that manages electricity demand in a sustainable, reliable and economic manner, built on advanced infrastructure and tuned to facilitate the integration of all involved.

Fig.2. Smart Grid Plane coordination system spanned by domains and zones [1]

A major enhancement of smart power grids on traditional grids is the independence of information flow from the power flow, which:

- Facilitates expanded deployment of energy sources
- Permits the accommodation of additional distributed power sources, to sustain further experiments
- Automated maintenance and operation
- Improves grid operability
- Enables transition to plug-in devices and new energy storage options
- Enables predictive maintenance and self-healing responses to system disturbances, improving reliability and security

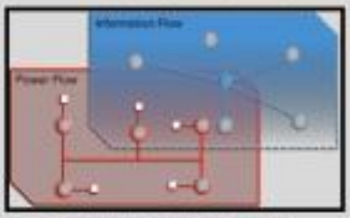


Fig.3. Power and information flow in a smart grid architecture [2]

Methods

- **Heritage Review:** terrestrial and space decentralized and modular power architectures (smart grid-like) are to be reviewed in this regard in order to identify synergies and transferable skills.

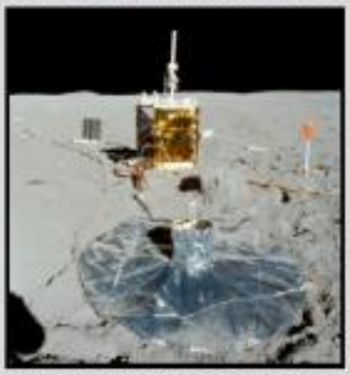


Fig.4. A partial view of the Apollo 15 Apollo Lunar Surface Experiments Package (ALSEP) in deployed configuration on the lunar surface. Credit NASA

- **Modeling:** Power generation, storage and flow modules will be modeled to be integrated into a unique grid like architecture. Figure 5 shows the Simulink model of a fuel cell capable of reproducing the Voltage-Current (V-I) and Power-Current (P-I) curves. The model computes the open cell voltage using the Nernst law and then subtracts the overall losses to calculate the output voltage of the cell.

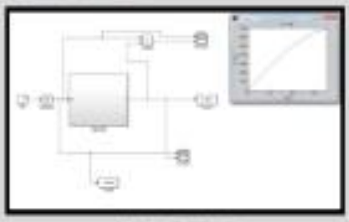


Fig.5. Fuel cell Simulink model

  - **Model Validation:** develop objective evidence that the designed model reflects the real-world application. The foremost model qualities required, towards this goal, are
    - Accuracy
    - Completeness
    - Consistency
    - Correctness
    - Testability

- **Software Development:** a main controller capable of managing the overall power and information demand and flow in a ‚smart' manner will be designed.
  - Software Validation: the foremost model qualities required, towards this goal, are:
    - Reliability
    - Operability
    - Maintainability

- **Hardware development:** breadboard level prototypes will be developed, using commercial of-the-shelf components, according to simulation results

- Testing:
  - Laboratory testing
    - Inspection
    - Functional tests
    - Fit check
  - Analogue field testing
    - According to mission scenario

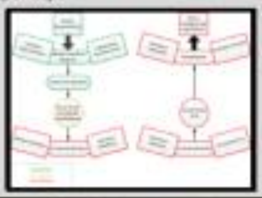
Baseline Design

The baseline of the smart power grid would compose a:

- **Power Generation domain:**
  - Solar panels
  - Regenerative fuel Cells
- **Power Storage domain:**
  - Batteries
- **Power Transmission**
  - Wired power transmission
  - Wireless power transmission
- **Power Management domain:**
  - Management and control system
  - Conversion and regulation system

Status Quo

- ✓ Mission Scenario Baseline
  - ✓ Scientific Requirements
  - ✓ Engineering Requirements
- ✓ Smart Grid Baseline
- Smart power Grid Model and Software
- ✗ Functional Baseline
  - ✗ Model Validation
  - ✗ Software Validation
  - ✗ Hardware Selection
  - ✗ Functional Test
- ✗ Smart Power Grid
- ✗ Breadboards
  - ✗ Hardware Validation
  - ✗ Develop Concepts



Conclusions

Execution of complex tasks in extreme, uncooperative and difficult-to-access areas, such is the moon environment, premise long term operations. A higher degree of autonomy in terms of energy supply, when realized as a smart, scalable and modular lunar outpost, could guarantee a wider and longer range of operations. Thus a smart grid like solution approach, for the power subsystem, is adopted. The development of such a technology is attempted through a number of steps:

- Initially, a literature review to asses the state of practice of space power and energy systems is conducted.
- Drawing upon this heritage, a conceptual baseline design is designed and modeled. Control algorithms are developed towards smart management of the energy resources.
- Based on the model results, hardware is developed to advance the state of the art in power generation, energy storage, power management and distribution for space applications.
- Finally, a breadboard level power system is then tested to be accommodated into an analogue mission scenario intended to demonstrate the developed technology.

References

[1] Ralf Apel, Smart Grid Architecture Model Methodology and practical application, [illegible]

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Development and fabrication of piezoelectric 0-0-3 foil composites

Dipl.-Ing. Marcus Kubicka[1] marcus.kubicka@dlr.de phone +49 (0) 531 295-2309
Dipl.-Ing. Maximilian Jux[2] m.jux@tu-bs.de phone +49 (0) 531 295-2285

[1] DLR - German Aerospace Center Braunschweig, Institute of Composite Structures and Adaptive Systems
[2] TU-BS - Technische Universität Braunschweig, Institute of Adaptronics and Function Integration

Ambitions and motivation

The main goal is the development of a CFRP system that monitors itself and reduces periodical maintenance and costs. Therefore an energy autarkic, sensorial nervous system comparable to that of human skin is needed. The idea is to fabricate a sensoric 0-0-3 piezoelectric layer for large area fiber composite structures which does not negatively influence the mechanical properties.

Compared to conventional piezoelectric ceramics, piezoelectric 0-0-3 foil composites have additional advantages. They are easy to handle, concerning their application and integration into complex structures. Especially their high flexibility, compared to standard PZT-sensors, makes them particularly suitable for complex curved structures. The composite fabrication is divided into shape forming and polarization. Typical used shape forming methods are hot pressing, rolling and extrusion.

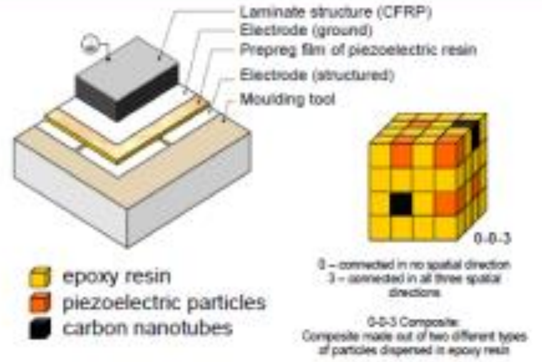


Figure 1: Layup and components of a piezoelectric foil composite

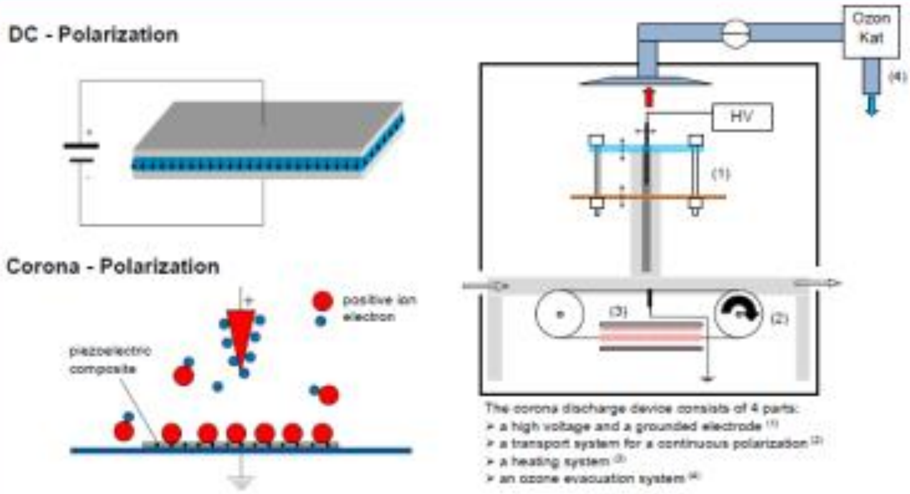


Figure 2: Schematic polarization methods and corona discharge device

Polarization

To polarize piezoelectric 0-0-3 foil composites large electric fields up to 20 kV/mm are needed. The reason for that is the low permittivity of the epoxy resin matrix which restrains the electric field. Two different methods for the polarization of piezoelectric 0-0-3 composites are used. On the one hand there is the conventional DC polarization method and on the other hand is the corona discharge method. The last one has several advantages compared to the first method:

- no dielectric breakdowns
- large-area polarization possible
- suitability for continuous polarization process
- reduced preparation time and costs

Current state and perspective

Piezoelectric 0-0-3 foil composites with different particle contents up to 80 weight percent PZT and up to 0,5 weight percent CNT are successfully fabricated. The polarization of these composite foils is realized with the DC and the corana discarge method (shown in Figure 2).

By deflecting CFRP beams with bonded piezoelectric 0-0-3 foil composites it is possible to get voltage signals of several hundred mV without any charge amplifier (shown in Figure 3). This demonstrates that these composites are suitable for sensor applications and structure compliant integration.

For the improvment of corona discharge polarization, future experiments will be performed with a heating device. One of the next steps is also the implementation of a material transport system to manage a continuous polarization process of piezoelectric 0-0-3 composite foils.

Figure 3: Fabricated piezoelectric foil composites

ROBEX

HELMHOLTZ GEMEINSCHAFT

Deutsches Zentrum für Luft- und Raumfahrt
DLR Institut für Faserverbundleichtbau und Adaptronik

Path Optimization with Respect to Thermal and Energetic Aspects for Rover and EVA Activities in Lunar Environments

Author: Dipl.-Ing. Matthias Killian

Technische Universität München, Lehrstuhl für Raumfahrttechnik, Boltzmannstr. 15 85478 München

Introduction

For autonomous or remote controlled rover operation it is necessary to plan the paths efficiently considering energetic and thermal aspects. The classic path optimization approach focuses on the total energy needs for locomotion. Further developed approaches also consider energy sources that are available during motion, such as solar radiation. However, there currently is no path optimization that includes the thermal infrared environment in detail into the calculations. This is not only important for highly sensible payloads on moving objects, but also for mobile soil sampling devices, that need to keep the sample in a controlled thermal environment. The transport of a regolith sample from a shadowed site to an illuminated area poses the risk of varying the initial temperature of the sample. Volatile elements that are trapped in the cold sample might be released during transport and hence the sample will loose its pristine state.

Previous work at TUM-LRT has shown that transient thermal analysis of a moving object on the lunar surface can help to simplify its design in thermal regards and offers significant advantages to a static worst case analysis. This method can be extended to thermal path planning, aiming to avoid thermal environments that are hazardous for payloads on a rover, sensible soil samples, or humans in spacesuits.

Objectives

The main goal of this thesis is to investigate path planning options with respect to thermal parameters. The lack of detailed thermal analysis within current path optimization tools limits the accuracy and path planning options within these tools. One aspect of this thesis therefore is the implementation of detailed thermal models in a path optimization tool. Ultimately the simulation aims to allow better and more efficient path planning with respect to thermal considerations. The thesis will focus on 3 main topics:

- Energy savings (less thermal heating/cooling needed)
- Mass savings due to less thermal control mass
- Thermal stability optimization (less thermal control mass for EVAs, sample transport, rover thermal control)

Methods

The simulation will be based on three components:

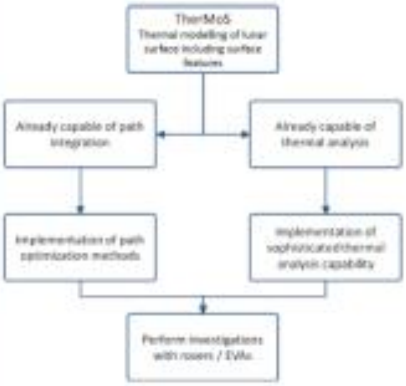
- Thermal modeling of lunar environment (in-house developed software TherMoS)
- Adaption of existing energy-focused path optimization codes (already existing for energy optimization)
- Introduction of detailed thermal models of moving objects (either extend TherMoS or use industrial software ESATAN-TMS)

By bringing these three components together it will be possible to simulate any mission on the lunar surface in thermal regards. A tool (TherMoS) for determination of lunar surface temperatures depending on solar angle, surface features (boulders and craters), and shading has already been established at TUM-LRT. It is also capable of thermal simulations for simple moving objects on the Moon. TherMoS will be the basis for the optimization tool. As a first step path optimization methods will be implemented in a new GUI that could be based on MATLAB.

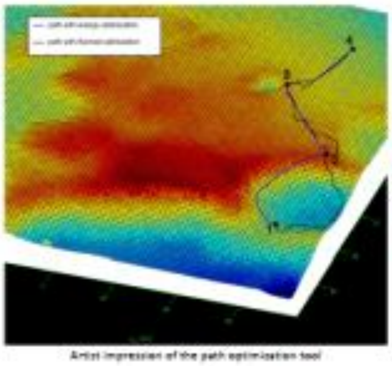
The most time-consuming process of a thermal analysis is the calculation of radiative heat transfer couplings between thermal nodes. Industrial software as well as TherMoS relies on ray-tracing to compute view factors for the radiative heat exchange. Speeding up computing time for ray-tracing is a critical element for thermal path optimization in order to calculate a reasonable number of path options. Another important improvement for accelerating the computation time is the enhancement of the thermal model solver itself.

Tools

The schematic shows the development plan for the optimization tool. The already existing TherMoS tool is capable of simulating the lunar surface thermally at any location on the Moon and at any date. Furthermore it is possible to implement additional thermal models (like a rover) and create a path by defining multiple waypoints.



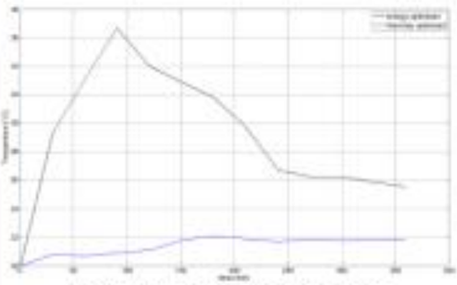
The capabilities of TherMoS have to be extended in order to conduct thermal and energetic path optimization. At first codes based on publicized data that deal with energy demand of paths will be adapted and refined to meet thermal path optimization needs. Additionally the newly developed tool has to be able to handle more complex thermal modelling. Those models could be integrated in this tool or through industrial software. Also a combination of both is possible. After the completion of the thermal path optimization tool, several investigations with moving surface-craft will be conducted. An artist impression of a possible path optimization result is depicted in the following figure.



Artist impression of the path optimization tool

Expectations

With analyses that will be conducted in the frame of this thesis it will be possible to quantify mass and power savings that are possible by thermal path optimization. Rovers as well as manned operations on lunar surface will be subjects to be discussed. The following plot gives an example for a rover motion on lunar surface. It qualitatively shows the temperature behavior of a regolith sample in a moving sampling device.

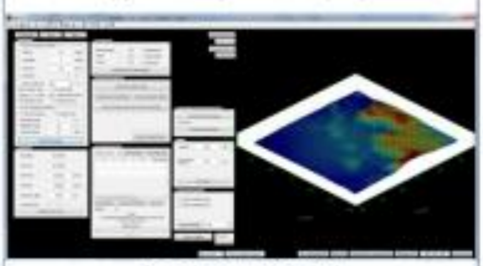


Temperature behavior of regolith sample during transport

The black line represents the temperature of an excavated regolith sample during an energetic optimized path and the blue line the temperature of the same sample on a thermally optimized path. It can clearly be seen that the temperature is more stable for the thermally optimized path. Of course this comes with some drawbacks as for example a longer distance and higher energetic costs for locomotion of the rover. These are the points that will be discussed and investigated in this thesis.

For manned activities, a path optimization with a detailed thermal model of an astronaut's spacesuit could lead to several positive effects. One of the most promising aspects is to decrease the mass of the thermal subsystem because less sublimation water can be used by an optimized path to meet thermal requirements of the spacesuit. Instead of decreasing the mass also the operation time could be increased by path optimization. As for the rover a balance between energy consumption and thermal stability has to be found and discussed.

Additionally a necessary task will be to find a way to accelerate the calculation time of thermal models. The most time consuming part in thermal simulations is radiative ray-tracing. Several possibilities will be investigated but the focus will lie on thermal model reduction. In order to accelerate the path optimization the calculation time needs to be decreased further. The reduction can be achieved by: reducing node sizes (mainly by focusing on the environmental nodes with the highest impact), increasing the ray-tracing velocity, and accelerating the solver routine (by the use of sparse matrices, etc.).



Picture of the current TherMoS tool

Dipl.-Ing. Matthias Killian
Technische Universität München
Boltzmannstr. 15 85748 Garching

Phone +49 (0)89 289 16008
Fax +49 (0)89 289 16004

email m.killian@tum.de
web www.lrt.mw.tum.de

Towards robust and adaptive locomotion of hexapedal robots

I. Motivation

Hexapedal robots are envisioned to be great platforms for terrestrial and extra-terrestrial exploration. Their great advantage is the versatility of properly designed and controlled legs. Besides enabling locomotion through very rough terrain, they allow to perform manipulation and tactile exploration of the environment. Even though articulated hexapods constitute a complex system, they provide redundancy and increased fault tolerance. The challenge with respect to robotic hexapedal locomotion is to robustly embed multiple locomotion modes, i.e. walking, running and climbing, in a single design while making it highly adaptive to varying environments and robot conditions. In the following the focus is on hexapedal walking and running.

II. Hexapedal walking

To achieve robust and adaptive hexapedal walking, an emergent, decentralized gait coordination is combined with joint torque measurement based reflexes and active joint compliance control. This enables our test platform, the DLR Crawler, to cross varying terrain while handling all obstacles within the walking height autonomously. Further, the gait coordination allows immediate adaptiation to leg loss.

Fig.1 DLR Crawler crossing steps

Fig.2 DLR Crawler walking across gravel

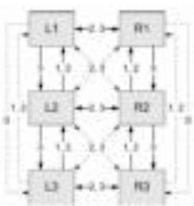


Fig.3 Extended gait coordination network

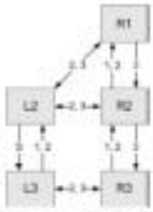


Fig.4 Adaptation to loss of leg L1

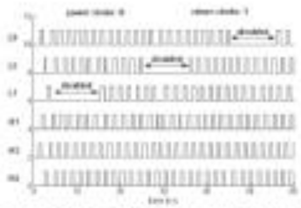


Fig.5 Gait pattern for different leg loss scenarios

Fig.6 Simulation with disabled left front leg

III. Hexapedal running

In order to design articulated legs that allow robust, self-stabilizing dynamic locomotion, their functional behavior needs to be understood first. For this purpose simulation studies with a simplified compliant planar model as well as a simplified compliant 3D model are performed. The goal of these studies is to identify the essential structural elements that result in rapid locomotion characterized by feedforward driven limit cycle oscillations.

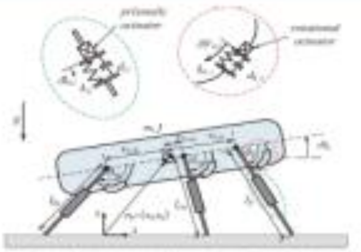


Fig.7 Planar hexapod model with serial elastic actuation

Exemplary results for the normalized model

1. Simulations show stable periodic motion

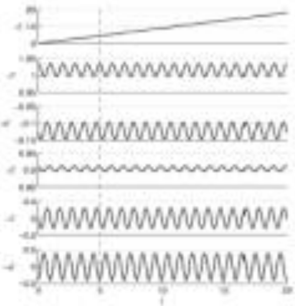


Fig.8 Body states

2. The running velocity is proportional to the feedforward actuation frequency

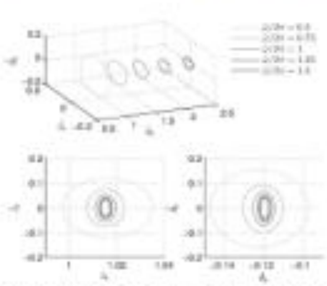


Fig.9 Periodic orbits in state space for different actuation frequencies

3. Ground reaction forces show functional specialization as observed for insects

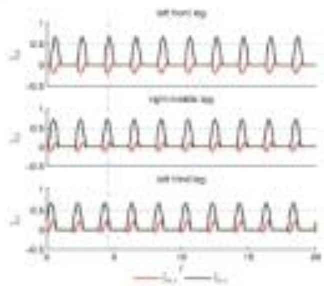


Fig.10 Ground reaction forces of the left tripod legs

References: [1] Görner et al. "The DLR-Crawler: a testbed for actively compliant hexapod walking based on the fingers of DLR-Hand II", Proceedings of IROS 2008, Nice, France, pp. 1525-1531
[2] Görner, Wimböck, Hirzinger, The DLR Crawler: Evaluation of Gaits and Control of an Actively Compliant Six-Legged Walking Robot, in Industrial Robot: An International Journal, 2009, Vol.36, No. 4, pp. 344-351
[3] Görner, Hirzinger, Analysis and Evaluation of the Stability of a Biologically Inspired, Leg Loss Tolerant Gait for Six- and Eight-Legged Walking Robots, Proceedings of ICRA 2010, pp. 4728-4735
[4] Görner, Albu-Schäffer, A robust sagittal plane hexapedal running model with serial elastic actuation and simple periodic feedforward control, Proceedings of IROS 2013, Tokio, Japan, pp. 5586-5592

Martin Görner
Robotics and Mechatronics Center
DLR – German Aerospace Center
Oberpfaffenhofen, Germany
Contact: martin.goerner@dlr.de

Deutsches Zentrum
DLR für Luft- und Raumfahrt

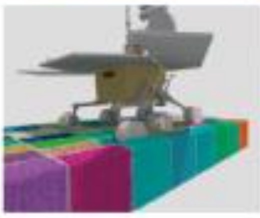
Echtzeit Mehrkörperdynamiksimulation mit Modelica

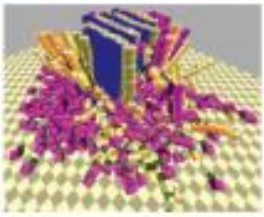
Vorstellung des geplanten Dissertationsthemas durch Matthias Hellerer

DLR

Problemstellung

Unterstützung des Entwicklungsprozesses robotischer Systeme durch Simulationen
Einheitliche, integrierte Simulation aller Teildomänen
Ende-zu-Ende Simulation des Gesamtsystems
Integration in vorhandene Entwicklungs- und Simulationsumgebungen





Anwendungen für moderne Mehrkörperdynamiksimulationen. Links: Simulation des Bodenkontaktes eines Marsrovers [4]; Rechts: Bullet Physics Engine Berechnet Kollisionen für 12 x 12 x 12 Würfel in Echtzeit.

Modelica

Modelica ist eine objektorientierte, gleichungsbasierte Modellierungssprache zur Beschreibung komplexer Simulationen über Domänengrenzen hinweg [3].

Beispiel für Modelica in einer Entwicklungsumgebung.
Links: graphische Ansicht; Mitte: Visualisierung der Simulation; Rechts: Modelica Code

Vergleich der Methoden

Newtonsche Mechanik	Mit Zwangskräften und Impulsen
+ Zwangsbedingungen werden immer exakt eingehalten	– Geringfügige Abweichungen möglich
+ Sehr effiziente Berechnung weicher DAE Systeme	–/+ Moderate Geschwindigkeit bei allen Systemen
– Kontakte verursachen ein steifes System (ineffizient)	+ Impulsaustausch sehr effizient möglich
+ leicht zu formulieren und zu analysieren	– Formulierung von Analyse kann schwerer verständlich werden
– Verbindungen sind zur Laufzeit unveränderlich	+ Dynamische Kontakte einfacher integrierbar
– Geschlossene kinematische Ketten müssen vom Nutzer getrennt werden	+ Geschlossene kinematische Ketten möglich

Modelica-Mehrkörperbibliothek

Die Modelica-Mehrkörperbibliothek ist Teil des Modelica-Standards.
Mehrkörperkontakte prinzipiell möglich, doch ist dies bis jetzt sehr aufwendig, rechenintensiv und nicht weitläufig im Einsatz [3,7,8,9].

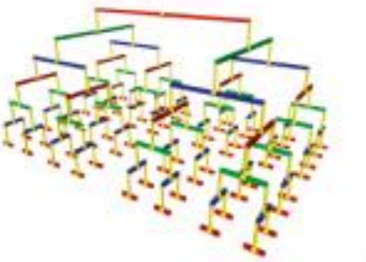
Kinderspielzeuge als Evaluierungsbeispiele für Mehrkörperkontaktdynamiksimulationen [1,2]

Alternative Berechnungsmethoden

Mehrkörperdynamik ist ein aktiv erforschtes Feld. Fortschritte in den Berechnungsmethoden erlauben:
Dynamische Kontakte
Große Zahlen von Objekten
Berechnung in Echtzeit

Berechnung mit Zwangskräften
Einzelne Objekte werden als freie Körper betrachtet.
Verbindungen (Gelenke, Kontakte) verursachen Zwangskräfte auf Körper.
Berechnung der Zwangskräfte als Optimierungsproblem [5].

Berechnung mit Impulsen
Statt Kräften werden Impulse genutzt (Produkt aus Masse und Geschwindigkeit).
Kontakte werden klassisch als sehr kurze Verbindung mit sehr hohen Kräften behandelt.
Effektivere Berechnung möglich als instantaner Impulsaustausch zwischen Objekten [6].



Einfache Beispielanwendungen. Links: 128 miteinander verkoppelte Kugelgelenken [2]. Rechts: Kugeln fallen auf eine konvexe Oberfläche wobei dynamische Kontakte entstehen und getrennt werden [5].

Ziele meiner Arbeit

Integration von neuen Berechnungsmethoden mit Modelica
Untersuchung der prinzipiellen Möglichkeiten und Limitierungen Modelicas
Erarbeitung möglicher Erweiterungen oder Anpassungen des Sprachstandards
Vergleich der Ergebnisse mit anderen Simulationen und realen Tests
Gestaltung eines virtuellen Testbetts für Rover

Anwendung in Robex

Bereitstellung eines virtuelles Testbetts für Rover erlaubt:
Rapid-Prototyping neuer Roverkonzepte
Verifikation von Konstruktionen
Objektive Vergleiche von Rovern bezüglich bestimmter Kriterien
Automatisierte Optimierung von Roverparametern in einem gegebenen Umfeld

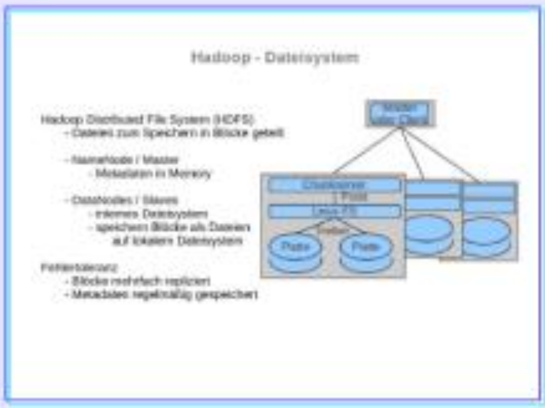
Rovertests in einem virtuellen Testbett; Links, Mitte: Im Rahmen von ROBEX entstandene Simulationen von Rovern. Rechts: Automatisierte Roveroptimierung in einem virtuellen Testbett [10].

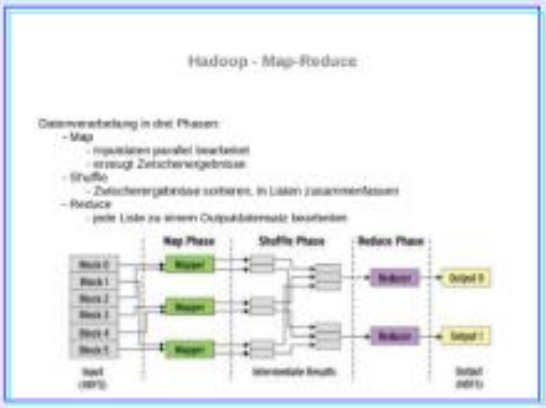
ROBEX
Robotic Exploration of Extreme Environments

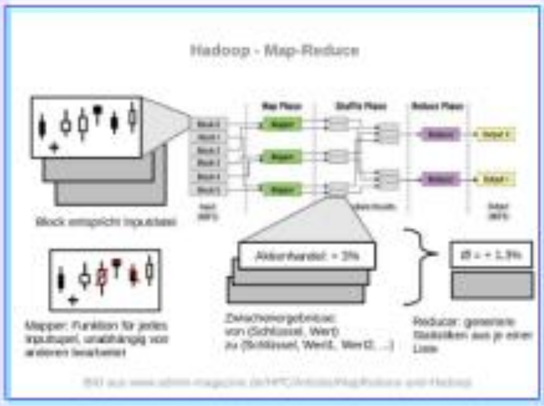
Big Data Analytics am Fallbeispiel der Finanzdaten

Nils Montenegro
Humboldt-Universität zu Berlin
Fraunhofer FOKUS
nils.montenegro@web.de

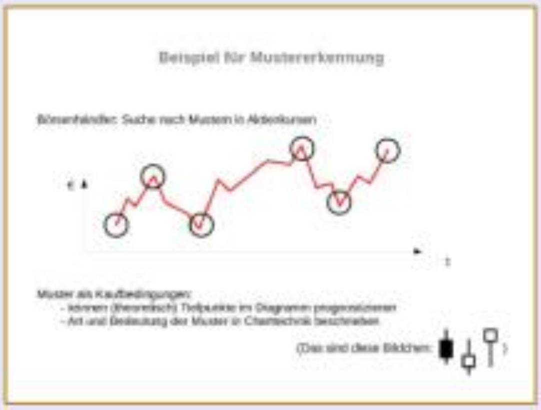
Big Data Platform

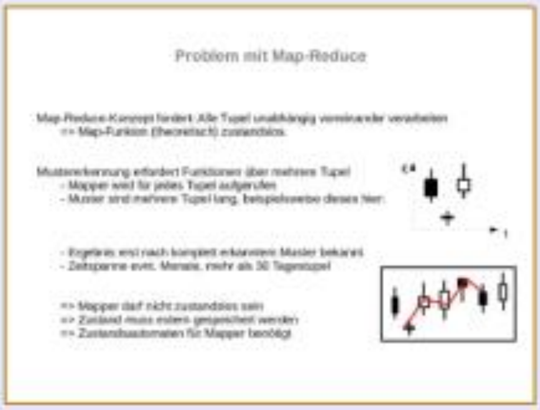


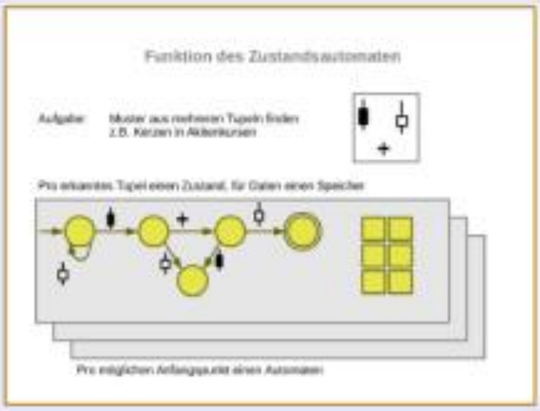




Beispielanwendung Finanzdaten Analysis







Autonomous Quadrocopter (AQopterl8)

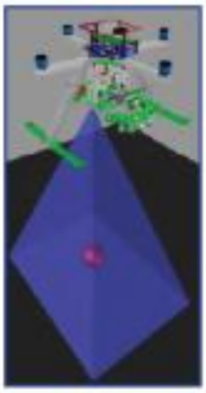
UAV World 2013

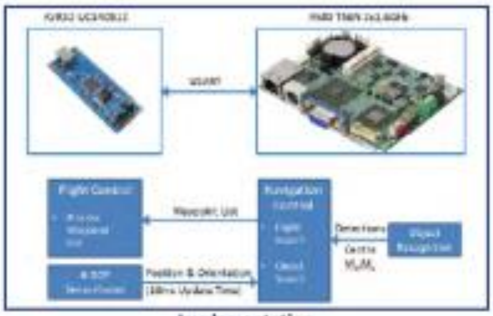
Project Goals

- fully autonomous quadrocopter
- low-cost components (sensors)
- robust operation in adverse environments
- complex missions:
  search, count, localize, map, etc.

AQopterl8

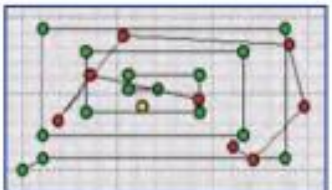
Search Mission
- autonomous start, fly & land
- scan iterativly search area
- add / reject detected objects





Implemantation

Reality



Result

Technical Requirements

- everything onboard: sensors, processors
- no external reference system
- optimised signal processing and control
- multi-sensor approach:
  - ultrasonic, radar (smoke)
  - infrared (soft flat one-color surfaces)
  - multiple camera sensors (complex surfaces, accuracy)

Hardware Design

Terms and Definitions:
- Field of View (FOV)
- Virtual Field of View (VFOV)
- Masking Area (MA)
- DFS (depth-first-search)
- BFS (breadth-first-search)
- Misses (M), Doubles (D)

Errors [cm]		DFS			BFS				
		Average			Average			Max	
MA	VFOV	dx	dy	E	X	Y	E	X	Y
15	25-35	Skipped			-19	8	21	32	24
	30-45	-17	16	24	-22	17	30	23	31
	40-60	-8	5	12	-13	9	18	23	17
	60-90	-6	9	11	-12	13	19	18	20
30	25-35	Skipped			-17	2	22	20	23
	30-45	-7	6	13	-17	17	25	28	32
	40-60	-23	8	24	-13	19	31	35	31
	60-90	-4	5	8	-7	-4	10	13	10
60	25-35	Skipped			-14	7	17	27	32
	30-45	-12	-8	13	-13	9	18	20	19
	40-60	-6	13	17	-17	11	21	24	21
	60-90	-16	15	22	-9	5	13	16	13
Average		-11	7	16	-15	10	20		

Detection failures		DFS		BFS	
MA	VFOV	M	D	M	D
15	25-35	Skipped		2	4
	30-45	0	2	1	0
	40-60	0	0	1	0
	60-90	2	0	4	0
30	25-35	Skipped		3	2
	30-45	0	0	1	0
	40-60	0	0	2	0
	60-90	2	0	4	0
60	25-35	Skipped		1	0
	30-45	0	0	1	0
	40-60	1	0	1	0
	60-90	0	0	4	0

Conclusion:
- DFS is better strategy, BFS fails
- accuracy: 15-20cm this limits MA
- search, count and localization of multiple objects was demonstrated

Universität Würzburg, Informatik 8, Am Hubland, 97074 Würzburg

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Als Projekt Lebensretter mit Propellern unterstützt von Universitätsbund Würzburg

Prof. Dr. Sergio Montenegro, 0931 31 83715, sergio.montenegro@uni-wuerzburg.de
Dipl.-Ing. Nils Gageik, 0931 31 83973 nils.gageik@uni-wuerzburg.de
Christian Reul

Julius-Maximilians-
UNIVERSITÄT
WÜRZBURG

Aerospace Information Technology

Basis (Wireless) Communication System and Radio Navigation

LPS-LaSi-Quad

Local Positioning System and Landingsimulator with Quadrocopters for Space applications

Knowing the position and orientiation of a spacecraft is a major concern in space missions. Precision alignment and its control needs to be performed within different contexts during a mission. Such situations could be e.g. the docking meneuvers of supply vessels or the landing of a spacecraft. Tracking one's own position can be done with onboard systems or with systems based on an existing infrastructure. Such infrastructure based systems are e.g. Galieo or GPS. Unfortunately there is usually no infrastructure at the desired destination which we can rely upon.

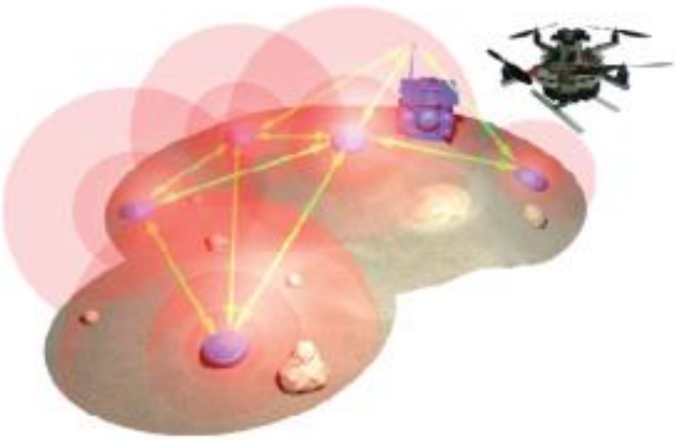


Fig. 1: The spacecraft brings its own infrastructure for localization. All concepts of the goal of the project can be veryfied with a quadrocopter based setup.

Therefore one aspect of LPS-LaSi-Quad is the development and testing of a technology that enables spacecrafts to bring their own positioning system to the destination. The spacecraft will carry it's own beacons to the destination and it will drop them over the target region. During initialization the beacons will determine their position to eachother. After initialization the beacons transmit signals which will be received by the spacecraft. Since the spacecraft will receive the signals with different phase angles, the system can compare the phases and calculate the exact position relating to the beacons.

Fig. 2: Beacon based positioning will be initially tested on the S.M.S - Satellite Manouver Simulator (right). Here an air cushion based S.M.S.-vehicle (left) can move in an 2D-setup between the beacons.

YETE

Physically Distributed Control System for Space applications

Today's avionics for spacescrafts uses wired electronics and many specialized computing nodes (Front-End-Computer) with varying processing powers. Each sensor and actuator is controlled by a dedicated Front-End-Computer. These subsystems are connected over a wired network with a bordcomputer or a payload-computer and their backup-systems.

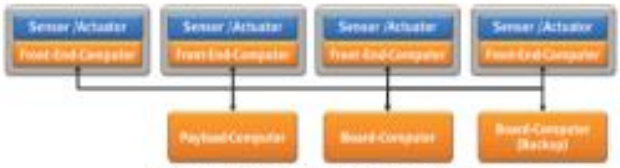


Fig. 3: Typical architecture of today's avionics

Though an entire avionics system could hold untapped ressources of computing powers, it cannot be shared easily among the nodes. A system with an overall capacity big enough to compensate unavailable processing hardware will not add any redundancy to a system as long as there is no robust and reliable way to absorb tasks of failing devices.

Fig. 4: Decoupling of sensor/actuator and computing hardware

One aspect of YETE is to decouple sensors/actuators and their corresponding processing nodes. In order to do so, generic computer nodes will be introduced. These nodes and the sensors/actuators communicate via a wireless connection. Since the nodes are generic, each node can take over the data processing of any sensor and its output.

Fig. 5: Wireless communication permits the control of sensors across system borders

Long-term objective is the realization of a fully distributed control across system borders including long range remote control (ground segment - space segment).

Prof. Dr.-Ing. Sergio **Montenegro**
sergio.montenegro@uni-wuerzburg.de

Dipl.-Inf. Tobias **Mikschl**
tobias.mikschl@uni-wuerzburg.de

M.Sc. Eng. Atheel **Redah**
atheel.redah@uni-wuerzburg.de

Dipl.-Ing. Nils **Gageig**
nils.gageik@uni-wuerzburg.de

cand. B.Sc. Richard **Pradeep**
pradeep.richard@yahoo.com

Dipl.-Ing. Alexander **Hilgarth**
alexander.hilgarth@uni-wuerzburg.de

DLR

Bundesministerium für Wirtschaft und Technologie

STANDARD INTERFACE
FOR LUNAR MODULAR ARCHITECTURES

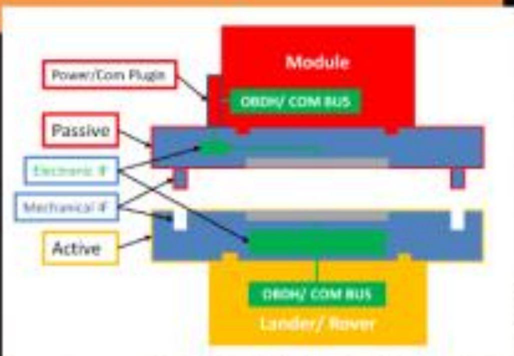
THE MISSION

- Placing two landing modules at Oceanus Procellarum
- The rover will detach the modules connected to the landers and fix them on the loading slots of the rover by using its manipulator.
- The rover will carry the modules, which include several seismometers and support systems, to their final destination and unload them. An active seismic experiment on the surface of the moon will be established.
- By doing this, the internal structure and composition of the Moon can be examined.
- Additionally, the mission shall demonstrate how to setup a modular lunar architecture.

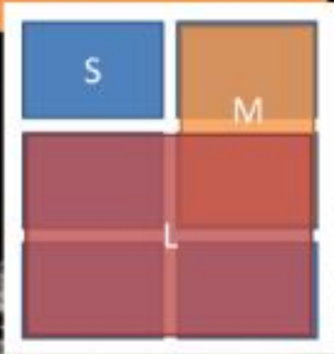
REQUIREMENTS

- Allows the fixation of different module sizes
- Safe locking mechanism
- Carry modules with up to 60 kg (weight on Earth)
- To be handled with manipulator
- Transmits data and energy, replaces plugs
- Resistant to temperatures of -150 °C to 150 °C
- Resistant to pollution by regolith
- Lifetime of 6 years

INTERFACE CONCEPT



MODULE SIZES



INDUCTIVE PLATES

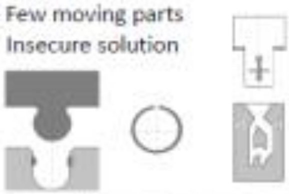
- Inductive plates transmit data and energy contact free
- Pollution by regolith decreases transmitting rate by only 0.2%
- Work also for deep see applications
- Saltwater decreases transmitting rate by only 1%

MECHANISM RESEARCH

LOOSENING BY OVERCOMING A RESISTANCE

- Roller pen
- Push to open mechanism
- Plug connections

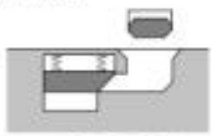
+ Simple mechanism
+ Few moving parts
- Insecure solution



LOOSENING BY DOING A COMBINATION OF MOVEMENTS

- Bayonet fixing

+ Unlocking by accident very unlikely
- High risk of tilting
- Difficult to handle with manipulator



DOOR LOCK PRINCIPLE

- Lock spring
- Twist lock

+ Maximum force depends on allowable stress in bolts
- High complexity
- Extra space on sides needed

CEDRIC WILLSCH

Student of mechanical engineering

Hochschule Niederrhein (Krefeld), university of applied sciences

DLR Bremen,
Institute of Space Systems
Robert-Hooke-Str. 7
28359 Bremen
Germany

cedric.willsch@dlr.de

SOURCES
Background image: NASA, Apollo 10, 1969
Top left: CE Study, DLR Bremen, Aug. 2013
Top right: CE Study, DLR Bremen, Aug. 2013
Mechanism Research: DRL Bremen, Feb. 2014

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