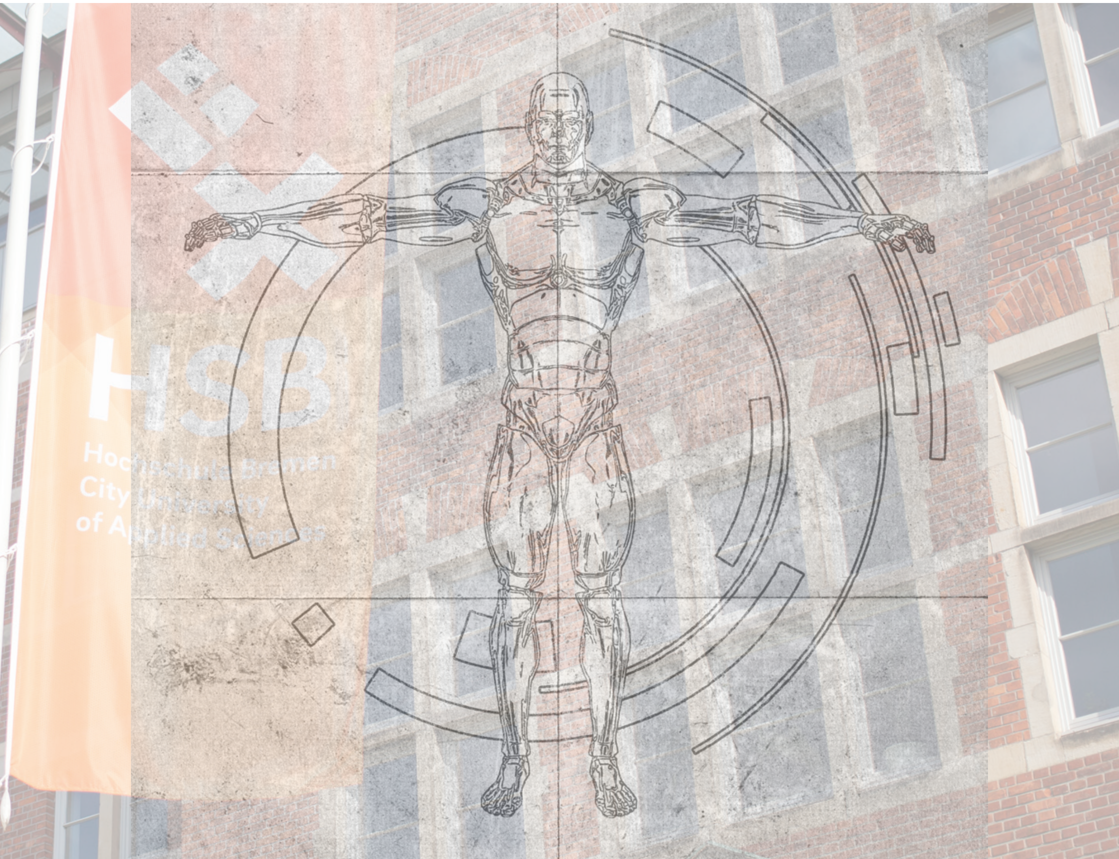
HSB
Hochschule Bremen
City University of Applied Sciences

Chinesisch-Deutsches
Zentrum für
Wissenschaftsförderung
中德科学中心

Integrated biomimetic robots - inspirations from biology for design, materials and control



4th Sino-German Symposium
on Biomimetics

3rd to 7th June 2019, Castle Etelsen

Contents

Welcome to Etelsen

Dear participant,

welcome to the 4th Sino-German Symposium on Biomimetics! We are very happy to see all of you here in Etelsen and spend this week together in an inspiring environment for scientific discussions, creative ideas and networking.

The previous three symposia have already had substantial impact on biomimetic research in China and Germany. The "Sino-German Symposium on Biomimetics" is starting to become a renown and respected platform for regular exchange and discussion between German and Chinese scientists.

The 4th symposium will now be building up on the topics of the previous symposia and allow participants to strengthen ongoing and explore new possibilities for colaboration between China and Germany in the various field of biomimetics. By bringing together the leading experts in their field we hope to expand ongoing scientific exchange and initiate additional cooperation programs.

We sincerely thank the Chinesisch-Deutsches Zentrum für Wissenschaftsförderung for funding this great opportunity for international collaboration. We wish all of you an interesting and rewarding conference.

On behalf of the organizing committee

Prof. Dr. Zhendong Dai (chair Chinese side)
Prof. Dr. Jan-Henning Dirks (chair German side)
Prof. Dr. Dorothea Brüggemann (co-chair German side)
Prof. Dr. Stanislav Gorb (co-chair German side)
Prof. Dr. Aihong Ji (co-chair Chinese side)

Some useful information

- **Location**: The conference venue is “Schloss Etelsen”, Bremer Str. 2 27299 Langwedel, phone: +49 (0)4235 9300-0.
- **Accomodation:** Room rates for all funded participants will be directly paid by the organizers. If you are self-funded, please settle your bill directly at the reception.
- **Food and beverages:** For all funded participants the costs for meals (breakfast, lunch, coffee and dinner) and softdrinks in Etelsen are covered by funding of the CDZ. Please note that by regulation of the federal state of Bremen expenses for alcoholic beverages are **NOT** covered by the CDZ. Should you wish to consume alcoholic beverages during the conference you can do so on your own expenses.
- **Check-Out:** On the day of your departure please check out and vacate your room before 9:00 am. You can leave your luggage at the reception.
- **WiFi:** Internet access is provided free of charge at Castle Etelsen.
- **Local travel to Bremen:** The city centre of Bremen can be reached conveniently within 20 mins via a direct train from Etelsen to Bremen Hbf (see figure 1 and figure 2). Trains from Etelsen run approximately every 30 min. The last train returning to Etelsen departs from Bremen Hbf at 00:13 am. Please check the website www.bahn.de for further information.
- Please regularly check the information board for updates during the conference. The staff at Etelsen will always be happy to assist you with any questions regarding the conference venue.

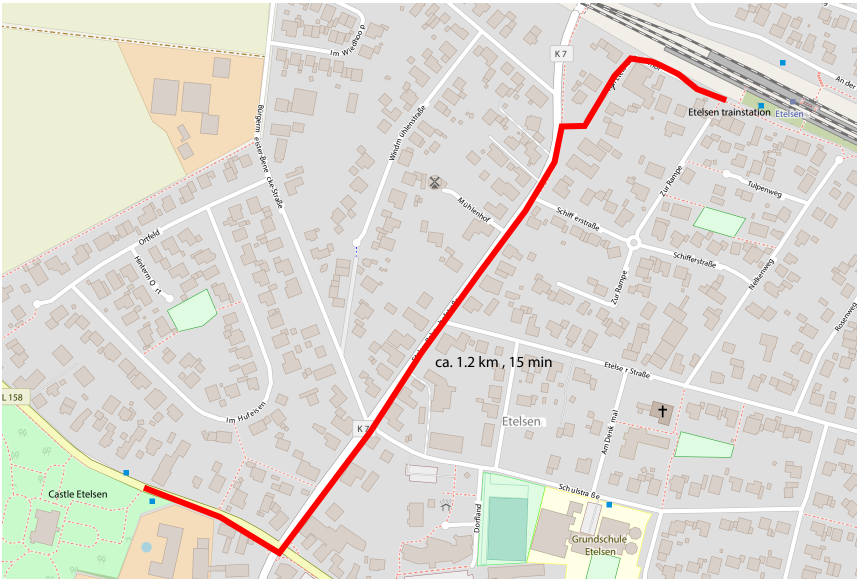


Figure 1: Directions from Castle Etelsen to Etelsen train station. The distance is about 1.2 km, which is a 15 min walk. Map data from OpenStreetMap.

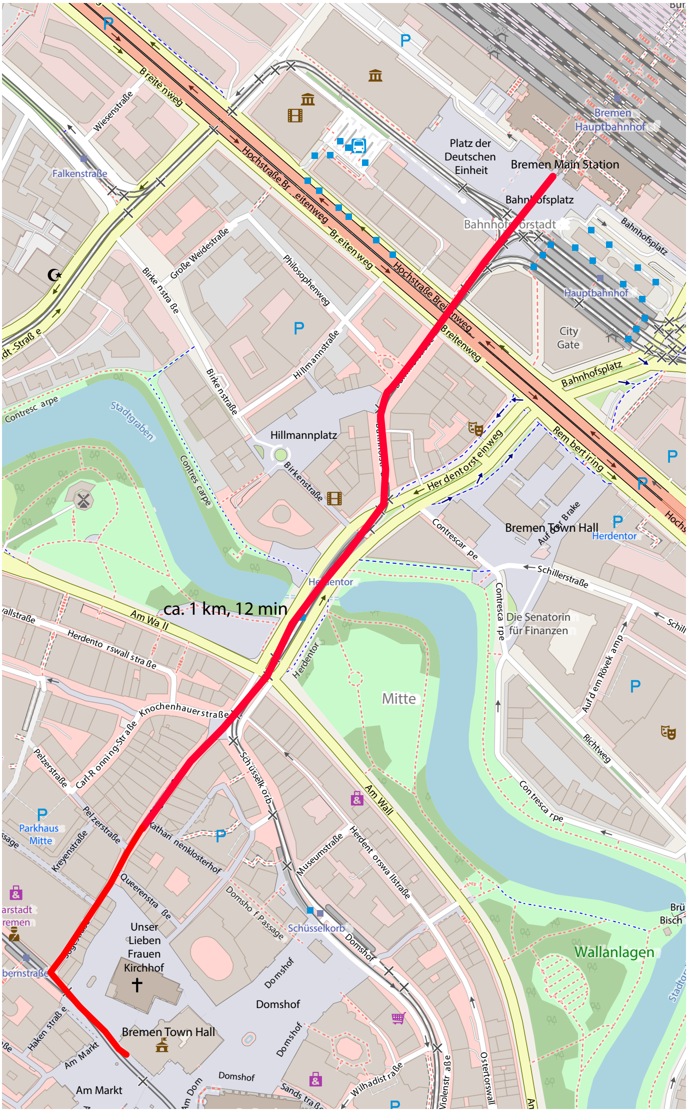


Figure 2: Directions from Bremen main station (Hbf) to the Town Hall of Bremen. The Soegestrasse is one of the main shopping areas in Bremen. The distance is about 1 km, which approximately takes 12 min to walk. Map data from OpenStreetMap.

Excursions

On Wednesday and Thursday afternoon we will visit selected sites representing the variety of scientific activities in and around Bremen. The transport will be via bus, starting and ending in Etelsen. There is no need to bring along your laptops, etc to the excursions.

On Wednesday evening our conferende dinner will take place in Etelsen after the excursion. On Thursday we will have dinner together in the Ratskeller in Bremen.

Alfred-Wegener-Institute, Bremerhaven

The main focus of the Alfred Wegener Institute (AWI) in Bremerhaven is polar research and the exploration of the sea. Scientists of different disciplines work together to investigate the climate, biosystems and geosystems. It is their common goal to achieve a better understanding of the complete system of our planet.

As an internationally respected centre of expertise on polar and marine research, the Alfred Wegener Institute is one of the very few scientific institutions in the world that are equally active in the Arctic and Antarctic. It coordinates German polar research efforts, while also conducting research in the North Sea and adjacent coastal regions in Germany.
Combining innovative approaches, outstanding research infrastructure and years of expertise, the Alfred Wegener Institute explores nearly all aspects of the Earth system – from the atmosphere to the ocean floor. In this regard, initiatives to better grasp the climate-related processes on our planet have increasingly taken centre stage.
More than 900 employees work at different locations of the AWI in Bremerhaven. The AWI campus encloses six complexes of buildings and various other buildings are distributed over the city. Source: AWI.

Klimahaus, Bremerhaven

Protecting the climate from a drastic, man-made change is currently one of the largest political and social challenges worldwide. Take a trip around the world and experience it's climate zones: From the refreshing coolness on the alp in Switzerland, through the scorching heat of the Sahel to the iciness of the Antarctic as well as the heavenly climate of the South Seas and the unsettled weather in Northern Germany. On the "journey" in the Klimahaus Bremerhaven 8° Ost visitors can experience first hand how the people live in the Earth's most important climate zones. The tour along the eighth degree of longitude East leads through sceneries that are built true to original locations.

Visitors to the “Switzerland” station can observe how climate change has already altered the lives of the people living in Isenthal today. A few exhibition sites further on, visitors to the “Cameroon” station are met with tropical heat. At night the West African rainforest offers fascinatingly exotic smells and sounds – and an insight into the deforestation industry. Cloudbursts and luscious green gorges await visitors in Satitoa on Samoa, before their route takes them through an impressive aquarium sea-world, which gives a fascinating view of a fringing reef of live corals. This journey reveals spectacularly how the lives of the humans on our planet are influenced by the climate and which changes are in store for us. This sensitises our visitors to targeted environmental and climate protection.

In 2012 the Klimahaus was recognised as part of the United Nations Decade of Education for Sustainable Development and in 2016 as well as in 2018 it received an award as a learning centre in the highest category of the UNESCO Global Action Programme on Education for Sustainable Development. The Klimahaus Bremerhaven 8° Ost works closely with partners such as the world-famous Alfred Wegener Institute for Polar and Marine Research, the Max Planck Institute for Meteorology and the Deutscher Wetterdienst (The German Meteorological Service). Source: Klimahaus Visitor Center.

Visitor information

- Although you will experience every climate zone in our exhibition ‘The Journey’, you will not need any special clothing for your visit to the Klimahaus! Although the exhibition areas are mostly warm, transition zones cushion temperature changes.

- Items such as large bags or rucksacks (max. 35 x 27 x 13 cm) are not permitted in the exhibition but can be left free of charge in the cloakroom. Coats can be left in the cloakroom for a fee of 1 €.

- You may take photographs of the exhibition for non-commercial use. However, please avoid using a tripod and a flash in the entire climate museum.

DFKI, Bremen

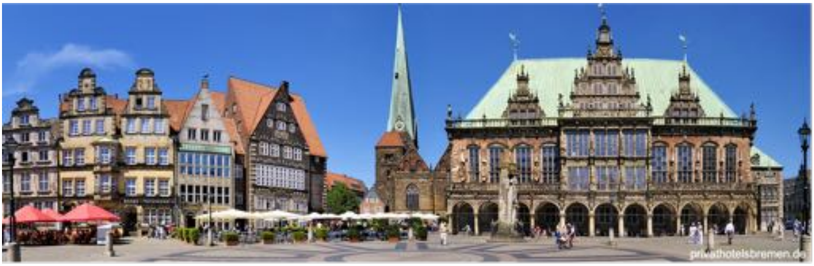
The DFKI Robotics Innovation Center is a young, dynamically growing field of research at the DFKI with international character. Currently, a staff of more than 110 employees from all over the world works here in research and development. More than 75 student assistants support the individual projects. The Robotics Innovation Center closely cooperates with the Robotics Group at the University of Bremen.

The Robotics Innovation Center team benefits from interdisciplinary cooperation: computer scientists and design engineers meet biologists, mathematicians, computer linguists, industrial designers, electro engineers, physicists, and psychologists in order to jointly develop mobile robot systems. The design accords to latest mechatronic developments and programming based on complex, massive-parallel embedded systems solutions.

In the framework of direct industrial orders or publicly funded joint projects, the Robotics Innovation Center designs and realizes intelligent robots for a variety of fields of application, such as underwater, space, SAR (Search and Rescue) and security robotics, logistics, production and consumer (LPC), cognitive robotics, e-mobility, and rehabilitation robotics. The focus lies on a rapid transfer of results of basic research into real-world applications. Source: DFKI.

Medieval City Centre, Bremen

Bremen, the cosmopolitan city on the Weser river, looks back on over 1,200 years of history. Although the grand old buildings around the market square betray its roots as an ancient trading centre, Bremen has the feel of a thriving city on the up.



The town hall and Roland statue are among Bremen's main historical attractions. They have enjoyed UNESCO World Heritage status since 2004 – as "an exceptional testimony to civic autonomy and sovereignty".

Bremen's Weser-Renaissance-style town hall with its magnificent facade is one of the finest civic buildings in Germany. It is the only European town hall built in the late Middle Ages that has not been destroyed or altered, managing to survive in its original form over the centuries.

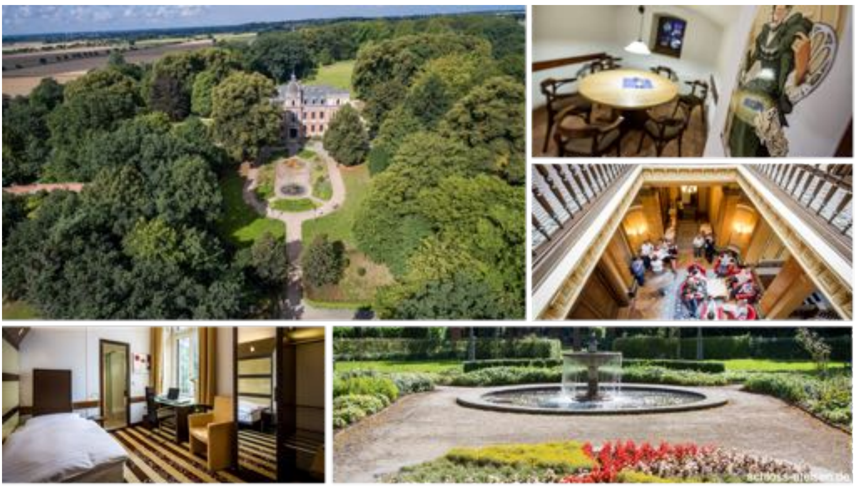
The figure of Roland is a global symbol of freedom and trading rights. Bremen's Roland statue is over 600 years old and it is widely regarded as one of the oldest and most impressive examples.

Incidentally, the cellar beneath Bremen's World Heritage site houses the oldest cask of wine in Germany. Known as 'rose wine' after the decoration in the cellar where it is stored, it dates from 1635 and actually tastes more like a sherry than a wine these days. Previously, the cellarmaster and the mayor were the only ones permitted to sample a few precious drops on occasion. But even they have been denied this pleasure since the town hall and Roland statue came under World Heritage protection. Source: Bremen Tourism Office.

Timetable

Sunday, 2nd June 2019

Time	
Afternoon	Arrival and Check-In of Chinese delegation
18:30	Dinner at Castle Etelsen



Monday, 3rd June 2019

Time		
Morning	Arrival and Check-In of German delegation	
11:00–11:30	Coffee break	
11:30–12:00	Opening of conference	
12:00–12:30	Prof. Sitti	Bio-inspired Small-Scale Soft Robotics
12:30–13:00	Prof. Wörgötter	Energy-efficient, adaptive control of complex robotic movements
13.00–14:30	Lunch	
14:30–15:00	Prof. Luksch	Of chicken, snakes and insects - neuronal and structural inspirations from nature
15:00–15:30	Prof. Stammhuis	Biomimetic Performance Enhancement of Wind Turbines
15:30–16:00	Prof. Xue	Stress regulation at separating interface for bioinspired dry and wet adhesions
16:00–16:30	Coffee break	
16:30–17:00	Prof. Chen	Dynamic liquid behavior on tree frog-inspired wet friction surface
17:00–17:30	Dr. Schaber	Fibrous materials for friction and adhesion inspired by the dry attachment system of the spider *Cupiennius salei*
17:30–18:00	Prof. Gorb	Functional role of gradients in biological attachment devices
18:30	Dinner (BBQ) at Castle Etelsen	

Tuesday, 4th June 2019

Time		
9:00–9:30	Prof. Brügggemann	Cellular biomimetics on the nano- and microscale
9:30–10:00	Prof. Colombi Ciacchi	An atomistic simulation approach towards biomimicry and synthetic biology
10:00–10:30	Prof. Wu	Bionic Hydrogels for Controlled Drug Release
10:30–11:00	Prof. Zhang	A bioinspired surface fabricated by surface tension assisted replica molding for unidirectional controllable liquid spreading
11:00–11:30	Coffee break	
11:30–12:00	Prof. Han	Bionic perception technology
12:00-12:30	Prof. Tang	Neurophysiological Characters Facilitate IR Imaging in Snakes
12:30-13:00	Prof. Bleckmann	The Fish Lateral Line as a Model for Biomimetic Flow Sensors
13.00-14:30	Lunch	
14:30-15:00	Prof. Döbereiner	Hydromechanical Signal Processing in *Physarum polycephalum Mesosplasmodia*
15:00-15:30	Prof. Yu	A Shadow Based Nano Scale Precision Force Sensor
15:30-16:00	Prof. Feng	Synergetic mechanical and geometric optimization of spider silk
16:00-16:30	Coffee break	

16:30-17:00	Mr. Focke	Investigations of biological samples using 3D X-Ray microscopy
17:00-17:30	Prof. Xiong	Research on humanoid robot: stable walking and intelligent manipulation
17:30-18:00	Prof. Guo	Bioinspired Separation Materials for Liquid Lubricants
17:00-18:30	Prof. Xu	Bioinspired Multi-Scale Pores and Channels
18:30	Dinner at Castle Etelsen	

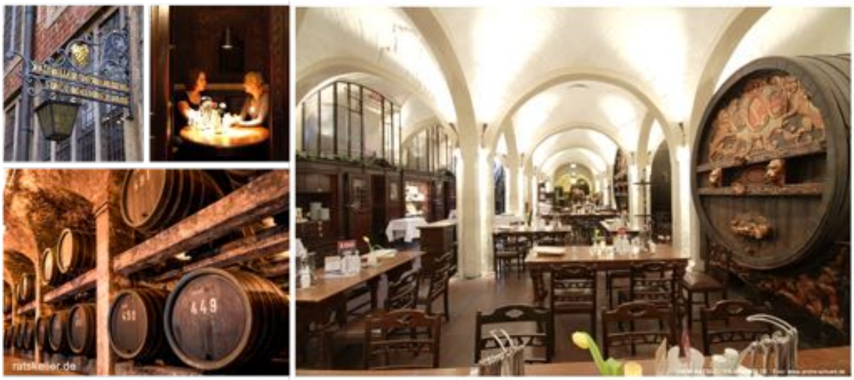
Wednesday, 5th June 2019

Time		
9:00–9:30	Prof. Wang	Introduction to the International Society of Bionic Engineering
9:30–10:00	Dr. Rajabi	From dragonfly wings to artificial wings of flapping robots
10:00–10:30	Prof. Müssig	Improved bio-inspired design through additive manufacturing
10:30–11:00	Mrs. Andresen	Improving vibration characteristics by using bio-inspired structures
11:00–11:30	Dr. Hamm	Innovation strategy for bionic lightweight optimization: from basic research to a software tool
11:30	Pick-up lunch bags and departure to Bremerhaven	
13:00–14:30	Visit Alfred-Wegener-Institute, Bremerhaven	
15:00–15:30	Arrival at Klimahaus, Bremerhaven and coffee break	
15:45–17:15	Guided tour Klimahaus	
17:30	Departure to Etelsen	
19:00	Conference Dinner at Castle Etelsen	

Thursday, 6th June 2019

Time		
9:00–9:30	Prof. Baars	Influence of geometry of dragonfly wing sections on lift and drag – A systematic study
9:30–10:00	Prof. Lehmann	Force control in flies
10:00–10:30	Prof. Dirks	Biological repair mechanisms – A new approach for biomimetic robotics?
10:30–11:00	Prof. Boblan	The elastic jumping mechanism of the grasshopper: Biology and active principle as well as application and control in an exoskeleton
11:00–11:30	Coffee break	
11:30–12:00	Prof. Schmitz	Adaptive motor control in insects walking on inclines
12:00–12:30	Prof. Schneider	Biomechatronics - The transfer of control concepts of moving biological systems to bio-inspired robotic components with special consideration of the substrate change
12:30–13:00	Dr. Berendes	Tactile exploration behavior of stick insects during straight and curve walking
13:00–14:00	Lunch	
14:00	Departure to Bremen	
15:00–16:30	Visit at DFKI, Bremen	
16:30	Departure from DFKI	
17:00	Guided tour through the historic city centre, Bremen	
18:30–21:00	Dinner at the Ratskeller of the historic town hall	

The Ratskeller of Bremen



Since 1330 the Council of Bremen held the privilege of white wine, which was valid until 1815. During this time no citizen was allowed to sell wine without permission of the Council. Therefore, all wines were stored in the central wine cellar of the Council, the “Ratskeller”. This, way the Council was able to control the prices and the taxing for wine. The Ratskeller holds a unique wine selection with about 650 different varieties of German wines.

The wine cellar is situated under the historic townhall of Bremen, which was erected in 1405. With its history over 600 years the Ratskeller of Bremen is one of the oldest wine cellars of Germany. Among its special sights you can visit the oldest wine barrel of Germany: a wine from Rüdesheim which dates back to 1653.

Friday, 7th June 2019

Time		
before 9:00	Check-out of German delegation	
9:00–9:30	Prof. Seidl	The desert ant as a model for robust odometry in legged robots
9:30–10:00	Prof. Dai	Biomimetic on gecko locomotion: Understanding biology for better design of gecko-mimicking robot
10:00–10:30	Prof. Ji	Limb forces in climbing treefrogs on a quasi-cylindrical tower
10:30–11:00	Prof. Xu	A Bio-inspired Wall-climbing Robot with Multi-locomotion Modes
11:00–11:30	Coffee break	
11:30-12:00	Mr. Wang	Kinematics of gecko climbing: the lateral undulation pattern
12:00-12:30	Prof. Labisch	Biomimetic locomotion - feasibility-studies with multibody simulation
12.30-13:00	Prof. Cheng	Strategy Study on Intelligent Maintenance for Fusion Reactor
13.00-14:30	Lunch	
14:30-15:00	Dr. Manoopong	NEUTRON: NEUrorobotic Technology for advanced Robot mOtor control
15:00-15:30	Closing of conference and departure of German delegation	
18:30	Dinner at Castle Etelsen	

Saturday, 8th June 2019

Time	
9:00	Check-out and departure of Chinese delegation

Please check the information board for details regarding your transportation back to Bremen airport.

List of abstracts

Improving vibration characteristics by using bio-inspired structures

Simone Andresen*, Christian Hamm

Alfred Wegener Institute Helmholtz Center for Polar and Marine Research, Bionic Lightweight Design and Functional Morphology, 27570 Bremerhaven, Germany

Investigating the influence of structural components on the natural vibrations of structures is of great interest in many fields of application including mechanical engineering, aerospace, construction and optics. The capability of a directed adjustment or increase of structural eigenfrequencies allows the avoidance of resonance phenomena without applying damping mechanisms.

Shells of marine protozoa show an enormous diversity of regular and irregular honeycomb and lattice structures which often fulfill different functions. The silicate shells of diatoms, for example, are characterized by a high stiffness at low mass and serve already as inspiration for lightweight designs. Furthermore, the irregular diatom structures are expected to have a positive influence on vibration characteristics.

In this research project, bio-inspired irregular lattice structures are used to improve vibration characteristics. Studies showed that increasing the degree of structural irregularity in lattice structures leads to significantly higher structural eigenfrequencies. In cooperation with the German Electron Synchrotron (DESY), a magnet underframe structure (girder) of a new particle accelerator is optimized by using bio-inspired lattice structures in order to achieve a high first natural frequency and stiffness at low mass. First numerical results indicate that the use of bio-inspired lattice structures leads to improved structural properties.

Influence of geometry of dragonfly wing sections on lift and drag - A systematic study

Albert Baars

City University of Applied Sciences Bremen, Biomimetic Innovation Center, 28199 Bremen, Germany

Wing sections of dragonflies exhibit corrugated profiles. Due to the low weight of their wings, they may serve as a model for Micro Air vehicles. The effect of these structures on aerodynamic forces has been investigated by various researchers. Up to know a more systematic variation of profile geometry and the impact on lift and drag are missing. In this study a wing section from literature is abstracted by a sequence of nine line elements. Length and arrangement of elements are calculated by a geometric series and the formulation of a NACA0010 profile. Parameters are length distribution of line elements (expansion factor $1.0 \leq r \leq 1.4$), camber ($0\% \leq m \leq 4\%$) and angle of attack ($-3° \leq \alpha \leq 3°$). Results are obtained by computational fluid dynamics for gliding flight. At a Reynolds number of Re $= 4000$ lift and drag coefficients are calculated and compared to those of wing sections of an original dragonfly and a NACA0010 profile. With growing incidence and camber an increase in lift and drag coefficient arises, which is in accordance with literature data. The distribution of line elements exerts a minor influence on aerodynamic forces in comparison to camber. These findings suggest, that for a given camber and incidence the distribution of line elements can be chosen according to the needs of mechanical wing stability.

Tactile exploration behavior of stick insects during straight and curve walking

Volker Berendes*, Volker Duerr

Bielefeld University, Dept. of Biological Cybernetics, 33613 Bielefeld, Germany

Many insect species use a pair of antennae (feelers) for tactile exploration of the near-range environment. As such, they may serve as paragons for the study of touch sensing in particular, and for the study of active sensing in the continuous interaction between animals and their environment in general. Owing to the physical contact of the sensory organ with the environment, tactile exploration is an interesting and equally challenging topic for biomimetic engineering, as well. This talk will introduce the key properties of the insect sense of active tactile exploration and touch, including some examples of touch-mediated behavior such as goal-directed reaching, and an overview of the known neural infrastructure involved. A focus will be laid on recent developments on direction dependence of tactile exploration and touch-induced turning. Finally, selected computational approaches will be discussed, that abstract key properties of the biological system and may lend themselves to implementation in biomimetic active touch systems.

The Fish Lateral Line as a Model for Biomimetic Flow Sensors

Horst Bleckmann*, Adrian Klein and Felix Kaldenbach

Institute of Zoology, University of Bonn, Poppelsdorfer Schloss, 53115 Bonn, Germany

Fish detect water motions with the mechanosensory lateral line. Lateral line information is used to avoid predators, track prey, and circumnavigate underwater objects. The basic unit of the fish lateral line is the neuromast, a sensory structure that consists of mechanosensitive hair cells enveloped in a gelatinous cupula. Lateral line neuromasts are distributed along the head, body and tail fin of fish, either superficially on the skin or in subepidermal canals that open to the water through a series of pores. Water motions external to the fish induce pressure driven water motions inside lateral line canals. This stimulates canal neuromasts which then signal the presence of external water motions to the fish's brain. We have built artificial lateral line canal systems. The biomimetic flow sensors used consisted of a transparent silicone bar located inside fluid filled canals equipped with canal pores. The silicone bar guided the light from a LED towards a position-sensitive photodiode. Fluid motions inside the canal deflected the silicone bar which was detected by the photodiode. The thickness and length of the silicone bar influenced both, the resonance frequency and the sensitivity of the artificial lateral line sensors. Sensitivity was also influenced by the length and diameter of the artificial lateral line canals. The distance between canal pores determined the spatial resolution of the sensors. The functionality of the sensors in detecting oscillatory fluid motions remained when we covered the canal pores with flexible membranes. Tension, diameter and thickness of the membranes altered the temporal filter properties of the artificial lateral line neuromasts. The density and viscosity of the fluid inside the artificial lateral line canals also influenced the sensitivity and temporal filter properties of the artificial lateral lines. The acquired knowledge allows us to optimize artificial lateral line systems for many specific technical applications.

The elastic jumping mechanism of the grasshopper: Biology and active principle as well as application and control in an exoskeleton.

Janine Kupfernagel, Mirco Martens, Johannes Zawatski, Alexander Pawluchin and Ivo Boblan*

Beuth University of Applied Science, Dept. of Electrical Engineering, Field Softrobotics, 13353 Berlin, Germany

Today passive upper body human support systems such as e.g. upper body exoskeletons are well developed by the materials used and the weights achieved and are already in practical trials. Passive systems for the lower body are still very heavily built from the material side and therefore impractical and bulky to use. The problem here is that as much as possible the entire weight of the payload as well as the arms should be discharged via the lower body exoskeleton to the ground. This results in the understanding of stability and strength to very stable structures, but which usually restrict the range of motion.

Actively driven support systems today, which do not limit the permissible loads of humans, the range of motion and the carrying comfort, you will not find at the moment. The problem here is that currently available actuators have limiting properties in terms of weight and / or media supply. We think that the jumping mechanism of the grasshopper (function and material) might provide a possible solution to answer the question of the relationship between (pay)load, torque production, and perfect timing including the material side. The task is to transform the underlying biological active principle into physical laws and to scale it by a factor of about 1000 so that useful insights and results remain. The literature and own experiments show that grasshopper can jump even with a higher weight than their own weight, without showing distinguishable abnormalities during takeoff, flight phase or landing.

Cellular biomimetics on the nano- and microscale

Karsten Stapelfeldt, Naiana Suter, Jana Markhoff, Dorothea Brüggemann*

Emmy Noether research group for nanoBiomaterials, Institute for Biophysics, University of Bremen, 28359 Bremen, Germany

Since billions of years nano- and microstructures control the function of biological systems in manifold ways. In particular, all cells in the human body are surrounded by a dense network of protein nanofibers, which forms the extracellular matrix (ECM). To design multifunctional cell scaffolds for regenerative medicine it is hence important to control the surface properties of future biomaterials on the nano- and microscale. However, due to its complexity, it is not possible to just "copy" the natural environment of a cell. Instead, to design novel biocompatible materials it is more important to understand the most relevant principles of the native cell environment and to transfer these principles into technical applications.

As a first step, our research in cellular biomimetics therefore focusses on the development of novel fibrous biopolymer scaffolds, which mimic the principles of the native ECM nanotopography to control cellular functions. One of our key techniques to prepare fibrous ECM scaffolds from various proteins on a large scale is a one-step extrusion process through ceramic nanopores. The resulting nanofibers can either be assembled into highly aligned fiber bundles up to millimetre length or into randomly oriented meshes. We also developed a new self assembly process to prepare bioinspired scaffolds from fibrinogen, which is a key player in blood coagulation and tissue regeneration. Using salt-induced self-assembly we fabricated nanofibrous scaffolds with overall dimensions in the centimeter range. Fibrillogenesis could be easily controlled and adjusted by salt and fibrinogen concentration as well as pH. Moreover, we established a novel biofabrication platform to prepare either immobilized or free-floating bio-inspired fibrinogen patches "on demand".

We believe that these and other now available technologies to produce nano- and microstructured scaffolds on a large scale will allow significant advances in actual technical implementation of "nano-biomimetic" principles in synthetic biology and regenerative medicine.

Dynamic liquid behavior on tree frog-inspired wet friction surface

Huawei Chen

School of Mechanical Engineering and Automation, Beihang University, Beijing, 100191, P.R. China

Strong wet attachment and friction of surface has attracted worldwide attention owing to its diverse potential applications in medical engineering, flexible electronics and medical engineering field. In contrast to well-known traditional wet friction, tree frog possesses an exquisite natural liquid adjusting mechanism to achieve stronger boundary friction. Such extraordinary wet friction function just results from its unique hierarchical pillar structure. SEM observation demonstrated that the hierarchical structure of toe pads possesses two-level hexagonal pillars and nano-cavity existing on the top of second-level pillar. From view of micro-scale interfacial liquid flow, two novel liquid adjusting phenomena were found in the interface, in which hierarchical hexagonal pillars generate liquid vertical self-splitting to automatically form uniform liquid film and nano-cavity arise formation of the liquid rim self-sucking. The wet boundary friction was greatly determined by the cooperative action of vertical self-splitting induced proportion enhancing effect (PEE) of strong liquid bridges and the self-sucking enhancing effect (SEE) on concave pillar. Inspired by the superior wet friction function of tree frog, we establish biomimetic surface design model that widen its applications in anti-slipping surgical grasper, strong attachment flexible electronics.

Strategy Study on Intelligent Maintenance for Fusion Reactor

Yong Cheng

Institute of Plasma Physics, CAS, Hefei, China

The fusion reactor will be characterized by the necessity of full remote maintenance for most of the critical components. Because no human intervention can be envisaged, the remote systems will have to prove high reliability and rescue capabilities. The availability of the fusion facility will have to be maximized, as a consequence, the efficiency of the maintenance equipment will become a key factor. However, currently the majority of fusion maintenance operations are conducted using man-in-the-loop techniques and under constant human supervision. In comparison, processes such as assembly and manufacturing are commonly automated in industry, and require little intervention from operators, dramatically increasing production and reducing costs. Hence, to carry out intelligent maintenance tasks in future reactor, a step change needs to be made from the current approaches ! The essence of Intelligent Maintenance for Fusion Reactor (IMFR) is to build a set of closed-loop enabling system based on state-aware data flow, featuring with state sensing, real-time analysis, scientific decision-making and precise actuation between cyber system and physical system, and to cope with the complexities and uncertainties in fusion environment to improve the efficiency of remote maintenance.

An atomistic simulation approach towards biomimicry and synthetic biology

Lucio Colombi Ciacchi

University of Bremen, Faculty of Production Engineering and MAPEX Center for Materials and Processes, 28359 Bremen, Germany

Fields of research as different as biomimetic materials synthesis, synthetic cell biology, or molecular biosensing all rely upon a common challenge; namely the accurate, atomic-resolved control of physical and chemical interactions taking place at hybrid biological and bio-inorganic interfaces. In our group we pursue a comprehensive modelling strategy that enables us to simulate the dynamical behavior and predict computationally experimental observables pertinent to such interfaces. Our simulations are based on advanced-sampling molecular dynamics based on all-atom force fields, and are accompanied by several experimental techniques, such as AFM force spectroscopy and circular dichroism. In this talk I will introduce the theoretical foundations and present recent applications of the methodology in the context of bioinspired functional materials synthesis, single-molecule biosensing and molecular trans-membrane transport. The advantages and limitations of the approach in predicting complex free energy landscapes and conformational phase spaces will be elucidated.

Biomimetic on gecko locomotion: Understanding biology for better design of gecko-mimicking robot

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Geckos have been studied for many years for their excellent moving abilities onvarious substrates. The paper reports our studies on the gecko adhesive mechanism, attaching and detaching dynamics, artificial adhesive materials and modification, gecko-inspired robot.Here we measured the contact/ tribo-electrifiction, results show that contact/tribo-electric charge between toes of gecko and substrate greatly influence the adhesion between setae and substrate. Our studies show that geckos prefer to detach from substrate by toe abduction, instand of peeling from substrate.Vertically carbon-nanotube array increase the adhesive, space circumstance heavily decrease the adhesive performance of polymer-based adhesive materials.We developed gecko-inspired robot and carried out experiments on micro-gravity simulating status.

Biological repair mechanisms – A new approach for biomimetic robotics?

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Any biological structure, from a single strain of nucleotides to a complex multicellular organism, is at constant risk of being damaged by its environment. From an engineering standpoint there are two possible strategies to face this challenge: either avoid damage or cope with damage. Several prominent biological examples illustrate the wide range of options available to avoid or at least minimize damage. Typical solutions include reinforced biological structures with high strength or materials with high fracture toughness and resistance to fatigue. In most cases however, investment into such "unbreakable" materials and structures can be costly. On the other hand, a commonly found alternative solution to the continuous threat of damage is the ability to fully or partially repair material and structures. Only investing into material when actually needed can be more efficient. In addition, remodeling of material allows for possible acclimatization to changing environments.

Repair in multicellular biological organisms can occur on several interlinked levels, starting from the sub-cellular via the tissue and organ levels up to the organismal level. In this presentation different repair mechanisms will be highlighted and discussed in respect to their evolutionary pathways and possible biomimetic applications to robotics. On which evolutionary levels did which repair mechanisms appear? How do these mechanisms depend on each other and interact? Are there any repeated patterns or repair mechanisms found across species and evolutionary levels? Investigating and answering these questions might help to understand and further explore general evolutionary trends in biological materials.

Hydromechanical Signal Processing in *Physarum polycephalum Mesosplasmodia*

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The slime mold *Physarum polycephalum* exhibits various topologies depending on environmental conditions. Well fed, it grows into an actively oscillating tubular transport network of veins. This network is capable of performing seemingly intelligent complex tasks like solving a maze, circumvent U-shaped obstacles, or react to periodic cues. Thus, Physarum has been discussed as a model of basal cognition. Starved, Physarum forms cone-like asymmetric mesoplasmodia with internal veins as an emergency response in order to search for food. We will discuss the unique motility mechanisms of this morphology. At the back end, lateral contraction waves pump cytosol through the veins towards the front. Veins form a cascade of forks acting as a low-pass filter resulting in isotropic extension of the cellular front. We analyze this effect within a lumped hydrodynamical model using an analogy to an electric circuit. The direction of movement is controlled via an asymmetry in the elastic modulus of vein tubules. We find a higher elasticity, i.e., a lower Young Modulus at the front. Foraging strategies and adaptive morphology as well as topology of Physarum polycephalum may serve as design models for building autonomous robots in aqueous environments. *Physarum amoebae* form robust entities capable to act alone or fuse to act as a collective depending on the task at hand.

Synergetic mechanical and geometric optimization of spider silk

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Owing to their exquisite geometric structures and excellent mechanical properties, spider orb webs possess an outstanding ability to capture flying preys. In this work, we explore the synergetic optimization of mechanical properties and geometric properties of spider webs. First, we report a mechanism that enhances the energy absorption ability of spider webs. Through systematic measurements of both spiral and radial silks, we find that the spiral silks feature a distinct gradient variation in the diameter and tensile stiffness along the radial direction of the web, while the radial silks have a much higher but approximately uniform stiffness. A mechanical model is proposed to reveal the functional gradient effects on the energy absorption of the web. This optimal structural feature of the web greatly enhances its efficiency and robustness in prey capture. Second, in addition to the widely recognized adhesion effect of the sticky glue, we reveal a synergistic enhancement mechanism due to the elasticity of silk fibers. A balance between silk stiffness, strength and glue stickiness is crucial to endow the silk with superior adhesion, as well as outstanding energy absorption capacity and structural robustness. The revealed mechanism deepens our understanding of the working principles of spider silk and suggests guidelines for biomimetic designs of spider-inspired adhesion and capture devices.

Investigations of biological samples using 3D X-Ray microscopy

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3D X-ray microscopy provides access to the internal microstructure and composition of materials under a variety of conditions and environments. The high-resolution X-ray focusing and detection optics enable the acquisition of tomographic datasets with resolution <700 nm. With the unique two-stage (geometrical + optical) magnification high resolution at large working distance is possible, opening up opportunities for interior (region of Interest) tomography of large samples as well as in situ and "4D" experiments using environmental cells. Further unique features of the Versa 520 are: (a) propagation contrast which allows the separation of material mixtures with low density differences and (b) contrast modes based on dual energy absorption or diffraction.

In the lecture we demonstrate the possibilities and advantages over common computer tomography which X-Ray microscopy offers for biological structures such as: (i) asteroidea (sea star); (ii) collembola (springtail) and (iii) locust (grasshopper). i Asteroidea (sea star): We investigated individual ossicle shape in unprecedented detail using X-Ray zoom techniques. The results show the variation of ossicle shape within ossicles of marginal, reticular and carinal type. ii Collembola (springtail): The Collembola (size 1 mm) were in silver-nanoparticles (AgNP)-contaminated water for several days. Multilayered cross sections from X-ray micrographs showed that silver was located in the mouthparts, claws, in the intestinal tract and on the surface of the animals. iii Locust (grasshopper): in this chapter we demonstrate the "Scout and zoom" technique using a grasshopper leg as an example. with a 20x lens we achieve a resolution of less than 3um without downsizing the leg.

Functional role of gradients in biological attachment devices

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Insects, spiders, and reptiles have developed elaborate attachment organs which allow them to attach reliably on a variety of different and unpredictable surfaces. By this combination of surface microstructures and material properties they are able to maximize real contact area and thus enhance their adhesive and frictional properties of animal feet. Whereas in smooth pads gradients of mechanical properties are well known, recent works on hairy adhesive systems in insects have revealed three important gradient-based features within individual hairs which allow for robust, reliable, and reversible adhesion. (1) The presence of a material gradient along the setae leads to an enhanced adaptability to rough surfaces and prevents clustering of setae. (2) The gradient of setal length from proximal to distal part of the pad is presumably responsible for uniform stress distribution in contact (3) The presence of joint-like elements within setae further enhances the adaptability and allows for robust adhesion. Here we will summarize structural, material, and functional gradients found in animal attachment pads. Moreover, we will present first experimental results on artificial mimics highlighting the importance of gradients for robust adhesion.

Bioinspired Separation Materials for Liquid Lubricants

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Friction is two faces, one is helpful for human beings, and the other is harmful, which can make a lot of loss for materials, energy, sizes and so on. Lubrication is an effective way to reduce friction by various kinds of lubricants. Among them, liquid lubrications are the most used due to their excellent properties, compared solid lubricants. Once water was mixed into the liquid lubricant, it will largely reduce the lubrication efficiency by hindering the formation of lubrication films and forming more serve corrosion wear for metal frictional pairs. How to remove water from liquid lubricants is still a challenge for us. Herein, some interesting researches will be introduced, which were done in our research group in the past six years. This will open a new route for the separation of oil/water mixtures.

Innovation strategy for bionic lightweight optimization: from basic research to a software tool

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The principles and underlying processes responsible for evolution and biodiversity of marine plankton organisms and their geometrically complex shells and exoskeletons are highly relevant and largely unresolved issues in the field of marine science. Among the most promising objects for the study of structual evolution are stable lightweight constructions, which occur in remarkable diversity among biomineralized marine protists such as diatoms or radiolarians. Profound research in these fields requires interdisciplinary expertises such as in 3D – microscopy and modelling, finite element analysis, paleontology, lightweight optimization, functional morphology, and marine ecology.

Much the same knowledge, completed by know-how in production engineering or lightweight architecture, is necessary to transfer knowledge on biogenic structures and evolutionary principles into new lightweight technologies. Research on new, sophisticated lightweight solutions is a strategically highly relevant research topic, especially as diminishing energy and material resources contrast with an increasing demand for mobility – both concerning people and goods. While numerous research institutes optimize of lightweight constructions using a pure engineering approach, new developments have shown that biologically inspired methods concerning optimization of structures and materials such as topology optimization, evolutionary strategic optimization, or ELiSE - the systematic use of structural lightweight designs of plankton shells - have proven their high potential to improve technical structures.

While each of these bionic methods has been successfully applied for prototypes or for products, a major obstacle has been the efficiency of the product development process for complex lightweight geometries, as the currently iterative approach involves multiple time-consuming steps in the fields of CAD, FEA and optimization. Here we show how a software can integrate these steps while using efficient construction principles from nature. The respective software ELISE can rapidly produce even very efficient, complex lightweight constructions which are needed in additive manufacturing.

Bionic perception technology

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In cruel environment, animals have evolved perfect mechanoreceptor to meet their survival needs such as preying capture, courting, and finding enemy. The mechanism underlying the biological receptor provides broad inspired strategies for designing brand new sensors. Scorpions are typically terrestrial nocturnal arthropods, which visual system have been highly degraded and deploy the ultrasensitive slit-based mechanoreceptor to detect substrate biotic vibrational signals several decimeters or even meters away from noise environment. In engineering field, crack, inducing enormous mechanical energy concentration at its tip, is considered as a typical kind of defect. Contrary to cognitions, we find that, to maximize the sensitive of slit-based mechanoreceptor, the near-tip stress field of "risky" crack-shaped slit is ingeniously used by scorpion to highly-efficient collecting tiny mechanical signal. In the process of mechanosensing, the dispersed tiny mechanical signal is highly-efficiently converged on nano-scale near-tip stress field at the anti-fracture crack-shaped slit tip and then converted into electric energy by mechanosensory neuron. In addition, the sensitive mechanism based on the near-tip stress field is further clarified by biomimetic mechanoreceptor. To investigate the stability of mechanoreceptor, the anti-fatigue resilin is found in the anti-fracture multilayered structure of mechanoreceptor through using the fluorescence analysis and toluidine blue staining. In addition, the cuticular membrane acting on the wake of pre-existing slit can effectively resist the crack nucleation from flaw-like slit tip under cyclic load. The synergistic coordination of the multiscale structure, material composition and micromechanical property well achieves the functional excellence and structural stability of mechanoreceptor, and maximizes its survivability. Inspired from the deformation of mechanosensory structure, the bio-inspired and crack-based strain sensor is designed through using oil paper and carbon black ink. The change of crack gap caused by external excitation leads to the change of sensor resistance, thus achieving the purpose of mechanical quantity detection. The gauge factor under weak strain was up to 647, three orders of magnitude higher than that of conventional metal strain gauge. The paper based bionic sensing element is used to recognize the motion gait of non-contact human body. The results indicate the motion details of human body can be identified and the motion information can be restored. The above study indicates the slit-based mechanoreceptor perfectly integrates the excellent performance of micro-scale, high-precision, anti-interference and low power consumption, providing biological inspiration for the next generation of bionic sensor with a broad range of applications.

Limb forces in climbing treefrogs on a quasi-cylindrical tower

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A new force measuring array with a quasi-cylindrical surface was designed to measure the three-dimensional substrate reaction forces of animals climbing on a surface with high curvature. This force-measuring array was assembled from 24 individual 3D force sensors, each with a resolution at the millinewton (mN) level, which were installed from top to bottom in four columns and six rows, with sensors in neighbouring columns staggered in height. Three cameras were used to simultaneously record the climbing behaviours of animals (in these experiments tree frogs) on the cylinder-like force measuring array. We were thus able to simultaneously record the ground reaction forces of each of the four limbs of tree frogs (here six individuals of the Chinese gliding or flying frog, Rhacophorus dennysi, with forelimb spans in the range 163-201mm) climbing or descending both smooth and rough surfaces on a quasi-cylindrical structure with an overall diameter of 79mm. We describe the design and calibration of the individual force sensors, their installation and arrangement on the quasi-cylindrical climbing tower, the recording of ground reaction forces and climbing behaviour, data transformations necessitated by the angular relationship of neighbouring sensors, and data processing using Matlab scripts. Additionally, we present preliminary data on the use of a clamping grip by climbing frogs and the existence of small pull-off forces that aid toe-pad detachment at the end of each locomotor stance phase.

Biomimetic locomotion - feasibility-studies with multibody simulation

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Evolution has optimized the locomotion of animals in different environments. So it seems easy to mimic this locomotion-patterns for robot-locomotion in similar environments. But it may become risky to build a robot identical to the documented movement-sequences of the animals. Only small deviations in the individual dimension lead to deflections in the movement patterns. Additionally it will not be possible to build a robot in the complexity the natural model shows. Several simplifications have to be carried out, but it has to be decided which. Therefore it is useful to transfer the robot concepts into a multibody simulation model in order to proof the planned dimensions, movements and constraints and to select the pertinent characteristics.

At the example of animal locomotions of a newt (*Pleurodeles waltl*), a crab (*Eriocheir sinensis*) and a cockroach (*Blaptica dubia*) the tasks and the transferred multibody simulation models are shown. The newt is able to swim in water and to move terrestrial. So it could be interesting to mimic its movement sequences to gain a simple but amphibian robot. The crab has turned out to be very fast in twisting around itself. So it could be interesting to mimic this strategy to implement a quick rotating manoeuvre of underwater vehicles. The cockroach is known to be a versatile runner also in onerous terrain. So it could be interesting to mimic its movement patterns to gain maneuverability and celerity also for the robot movement.

Force control in flies

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Rhythmic locomotor behavior in animals requires exact timing of muscle activation within the locomotor cycle. In flying insects, this precision of motor commands is highly relevant in a large context of various behaviors, including stabilization of body posture, heading control and directed escape responses. However, in rapidly oscillating motor systems, such as flapping flight of flies, conventional control strategies may be affected by neural delays, making these strategies inappropriate for precise timing control. In flies, wing control thus requires sensory processing within the peripheral nervous system, circumventing the central brain. The lecture tackles the underlying mechanisms, with which flies integrate graded depolarization of visual interneurons and spiking proprioceptive feedback for precise muscle activation. A numerical model of spike initiation in flight muscles of a blowfly suggests that motoneurons may play a significant role for sensory integration and graded muscle power control. The simulated Hodgkin-Huxley neuron reproduces multiple experimental findings and explains on the cellular level how vision might control wing kinematics. The findings are eventually discussed in a larger context, including neurobiological and aerodynamic perspectives on insect flight control.

Of chicken, snakes and insects – neuronal and structural inspirations from nature

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In our group, we analyse various biomimetic aspects of animals. For sensory processing, we study the computation of different modalities in vertebrates and particularly analyse the processing and integration of (multi-)sensory information in the brainstem networks. As an example, the specialized infrared sense of several species of snakes are of particular importance as the infrared system represents a simple receptor structure that resembles visual image formation, and the integration may thus yield principles to integrate systems with different precision optimally. In addition, we study the motor behavior of snakes, to understand the motor control networks that enable a multi-joint system to function appropriately. In an avian model, we study the localization of stimuli in space with a combination of sensors, and analyse the neuronal processing in a computational map in the midbrain. In a separate line of research, we are looking at insect cuticular structures, the variety of which still offers surprises and options for functional surface structuring in technical systems.

NEUTRON: NEUrorobotic Technology for advanced Robot mOtor control

Poramate Manoopong

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Walking animals show adaptive, versatile, autonomous behaviors. They are able to perform a variety of movements and adapt their movement according to the changes of their morphology and the environmental conditions. Biological studies suggest that these emergent properties are realized by biomechanics, distributed central pattern generators (CPGs), local sensory feedback, and their interactions during body and leg movements through the environment. In this talk I will present how we use this inspiration to develop our neurorobotic technology for advanced robot motor control to scale up from basics of self-organized sensorimotor coordination to locomotion and object manipulation of bio-inspired walking robots.

Improved bio-inspired design through additive manufacturing

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In this work, the bilateral relationship between 3D printing or additive manufacturing (AM) and biological structures will be discussed. AM enables a structure-focused, "growth-like" manufacturing process for designed products and objects in strong analogy with nature's way of creating. Nature's organisational structure reaching from molecules over organelles and cells to organs, organisms and whole eco-systems is resembled in the use of polymers, thermoplastic wire, polymer melt, deposited layer, finished part and supply chains in Fused Deposition Modelling (FDM), currently still the most common type of 3D printing. As a result, it has become possible to realise highly complex bio-inspired and bio-mimetic structures and designs.

AM also allows new perspectives on understanding biological structures and their generation. This understanding is a crucial step in bio-inspired design and engineering and is often neglected as reproduction of organisms or parts thereof by traditional means is often difficult and/or cost-intensive. In turn this leads to an incomplete translation of observed biological principles and as a result a loss in value of the design. By using AM technology it has now become possible to accurately reconstruct living organisms and tissue without any processing related concerns. Consequently, a better and more precise understanding and translation of biological principles has become possible leading to improved designs and products.

While promising this development is currently hindered by a lack of materials suitable for AM. A crucial next step is the development of new materials that allow for further improvements in the translation of biological principles in bio-inspired designs. We will review current developments at the intersection of AM, bio-inspired design and material development and discuss the most successful examples to date.

From dragonfly wings to artificial wings of flapping robots

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Dragonflies are one of the most successful flying insects. Their success, to a large extent, is attributed to the complex design of their wings. The wings consist of several structural components which passively control wing deformability under external forces experienced during flight. This enables the insects to generate aerodynamic lift, which in some cases exceeds several times their body weight. The level of the automatic shape control achieved by wing design, makes dragonfly wings ideal models for bioinspired design of artificial wings for flapping robots. Here we present the results of our research on complex wings of dragonflies. Our aim is to establish a link between the structure of wing components, such as membrane, vein, microjoints, etc., and their function in relation to other components in the whole wing system. By putting them together, we explain how our findings can be used to enhance the efficiency and durability of wings of existing flapping robots.

Fibrous materials for friction and adhesion inspired by the dry attachment system of the spider *Cupiennius salei*

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Vertically aligned carbon nanotube (VACNT) arrays and free-standing anchored cellulose nanofibrils (CNFs) from plant seed mucilage are candidate materials to find materials with tribological properties similar to the remarkable biological model attachment systems, such as those of the legs in hunting spider *Cupiennius salei* or on the feet of the gecko. To gain insights into the relationship between the friction and the adhesion forces and the underlying structure of the fibrous materials, both the spider's attachment hairs (setae) and the artificial materials were examined using micro force sensors, tribometers, and different microscopic techniques. The spider attachment system comprises hundreds to thousands of up to 800 μm long setae, arranged roughly in parallel, and located in a pad-like structure facing the substrate. Each seta is hierarchically organized with thousands of approximately 1 μm wide microtrichia branching off the main structure. In the tip region of the setae, these microtrichia end in the approximately 20 nm thin spatula-shaped adhesive contact elements. Upon attachment, these contact elements align with the surface of the substrate leading to attractive van der Waals forces. With diameters of 5–20 nm and 15–40 nm, the dimensions of the VACNTs and CNFs are in the same range. The coefficients of friction on the surface of the VACNT arrays are as high as 5–6 in the first sliding cycles, and constantly 2–3 in the consecutive sliding cycles. These values are among the highest coefficients of friction ever reported. With friction coefficients in the range between 1 and 3, friction is also remarkable on the CNFs arrays. These high values can be explained by the same mechanism of alignment of the fibers with the sliding counterpart as in the biological model. However, adhesive forces at normal pulling-off were never observed. A big difference between the two artificial surfaces is their production. Whereas the VACNTs are synthesized at high temperatures in a chemical reactor, the CNFs can be produced more environmentally friendly just by hydration of the seed followed by critical point drying. We suggest the potential of both artificial surfaces where high contact forces to surfaces are desired, especially in dry environments. However, to reach a performance similar to the biological model, more research is needed to transfer the biological building principles to the materials for specific applications.

Adaptive motor control in insects walking on inclines

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The ability to adjust leg muscle activity to changes in the mechanical demand acting on the body is critical for terrestrial locomotion in erratic environments. During walking and climbing, the mechanical demand can vary considerably from one step to the next. For example, while the gravitational force pulls the body toward the surface during level walking, it pulls the body backward during uphill walking and forward during downhill walking. How are leg muscle activities and leg movements adjusted to adequately propel and stabilize (balance) the body in these situations?

In the case of insect walking, understanding the underlying control is limited because little is known about how leg muscle activity changes with leg kinematics (movements) and leg dynamics (forces, torques) in different walking situations. We approached this issue by combining electromyography with high speed motion capture and ground reaction force measurements in hind legs of stick insects (*Carausius morosus*) walking freely on level ground and up and down inclines (±45°). We found that kinematics including leg joint angles, body pitch and height varied little across inclines, although dynamics revealed substantial changes in mechanical demand. During downhill walking, for example, horizontal leg forces and torques at the thorax-coxa and femur-tibia joints reversed in sign. At the thorax-coxa joint, the altered mechanical demand was met by adjustments in timing and magnitude of antagonistic muscle activity. Adjustments occurred primarily in the early stance after the touch-down of the leg. When insects transitioned from level to incline walking, the characteristic adjustments in muscle activity occurred with the first step of the leg on the incline, but not in anticipation. Together, these findings indicate that stick insects adjust leg muscle activity on a step-by-step basis so as to maintain the same kinematic pattern under different mechanical demands. The underlying control might rely primarily on local feedback from leg proprioceptors signaling leg position and movement. Transferring this controller scheme into the controller algorithms used to control our six-legged robot HECTOR may have the advantage that we will not need high-capacity data processing in a central processing unit with global knowledge. Rather, it can be implemented as local reflexes from which global motion intelligence is expected to emerge.

Biomechatronics - The transfer of control concepts of moving biological systems to bio-inspired robotic components with special consideration of the substrate change

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One of the main foundations for the versatility and flexibility of the animal and human biomechanical systems are their adaptive actuator systems composed of a multitude of different muscles of variable layout and behaviour fitted for each joint. The musculoskeletal system and its neural control allows – on the one hand – fast, powerful, and elastic movements, but – on the other hand – also the manipulation of objects with high precision. Many animals control their muscles by means of neuronal signals generated by motoneurons. Motoneurons, together with their corresponding enervated muscle fibers, form motor units which are at the end of a communication chain that conveys deliberate movement commands from higher brain areas. The concept of Biomechatronics deals with the improvement of moving technical systems e.g. by abstraction of the above mentioned mechanisms from biological models and their implementation on the basis of suitable technological substrates. In this context, various highly integrated, bio-inspired drive and sensor systems have already been developed in the workgroup of the author. Corresponding control schemes have been designed and implemented on the respective embedded hardware. One tangible result of these efforts is the bio-inspired walking robot HECTOR. The talk provides an overview of the concept of distributed motion control and its implementation on decentralized hardware as it is used on HECTOR. In this approach, the high degree of sensorization is in the focus for the realization of reflex-like control components as observed in the biological example. Based on this, it will also be discussed how approaches of bio-inspired, muscle-like motion control, as used on walking robots, can also be transferred to wearable robotics. Here, the model-based integration of bio-signal measurements plays an important role in the use of muscle-like motion control and the prediction of limb movements.

The desert ant as a model for robust odometry in legged robots

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Navigation is a major challenge in real world mobile robot applications – even more so in the absence of reliable external support cues. This challenge increases significantly in legged robots. Robustness and redundancy are key features – preferably at little cost in terms of payload and energy consumption.

The desert ant *Cataglyphis fortis* is a model animal for robust egocentric navigation. It copes with slippery terrain in the blazing mid-day heat with little to no landmark-guidance and yet returns safely to its nest. To do so it derives directional cues are derived from polarized light patterns and – more importantly for technical application – distance and inclination cues through proprioceptive signals.

Here we report on our activities to derive a generic engineering concept of the ant's odometer. Based on the campaniform sensilla - central for locomotion control in insects - a simplified technical approach uses joint torques as a correlate of leg loading. We evaluate the application potential of ant based odometry using both simulation and hardware approaches: Three-dimensional kinematic leg-trajectories are translated into joint torque angle and used to drive a custom built robotic leg walking on treadmill. Joint torques are derived from the current in the driving motors. Strain gauges near the joints are used for comparison. A pressure sensor in the end effector allows monitoring the ground reaction forces. Currently the influence of different inclinations, walking speeds, geometries and kinematics on the resulting torques are investigated on the setup.

The measurements are then validated in a multibody simulation and compared with a near-natural simulation. Both leg simulations are assembled into a hexapod arrangement to measure real ground reaction forces and joint torques. Preliminary results show that the data can be used to construct a generic engineering concept. Future work focusses on data fusion and deriving odometry information by employing biologically plausible artificial neural networks.

Bio-inspired Small-Scale Soft Robotics

Metin Sitti

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Inspired by soft-bodied animals, soft functional active materials could enable physical intelligence for small-scale (from a few millimeters down to a few micrometers overall size) robots by providing them unique capabilities, such as shape changing and programming, physical adaptation, safe interaction with their environment and multi-functional and drastically diverse dynamics. In this talk, our recent activities on design, manufacturing, and control of new bio-inspired shape-programmable active soft matter and untethered soft robots at the milli/microscale are reported. First, elastomeric microfibers, inspired by gecko foot-hairs, are proposed as new reversible soft adhesives for robotics, as soft robotic gripper and climbing robot attachment materials, skin adhesives for soft wearable devices, etc. Second, red blood cell (RBC)-based soft microswimmers driven by attached E. coli bacteria are proposed as new active local drug delivery systems. These microswimmers carry cargo such as drugs and imaging agents inside the RBC, can be steered magnetically, and can be fully degraded via exposed NIR light. Third, untethered soft millirobots inspired by spermatozoids, caterpillars and jellyfishes are proposed using elastomeric magnetic composite materials. Static and dynamic shapes of such magnetic active soft materials are programmed using a computational design methodology. These soft robots are demonstrated to be able to have seven or more locomotion modalities (undulatory swimming, jellyfish-like swimming, water meniscus climbing, jumping, ground walking, rolling, crawling inside constrained environments, etc.) in a single robot for the first time to be able to move on complex environments, such as inside the human body. Preliminary ultrasound-guided navigation of such soft robots is presented inside an ex vivo tissue towards their medical applications to deliver drugs and other cargo locally and heat the local tissues for hyperthermia and cauterization.

Biomimetic Performance Enhancement of Wind Turbines

Eize J. Stamhuis

ESRIG (University of Groningen) & DEpt of Biomimetics (UAS Bremen)

Both middle-sized as well as large wind turbines that are used for larger wind parks on land as well as at sea deliver their nominal power effectively only at wind speeds of 12 m/s or higher. In practice the average wind speed in the European coastal areas is usually between 5 and 7 m/s. This causes the wind turbines to under-perform and causes low energetic yield. Research at Albatrosses and Fulmars has shown that at low relative airspeeds, mostly during take-off and landing, the wing oscillations that these bird apply cause significant increases in the aerodynamic lift forces. This principle has been tested thoroughly with wing models in both flow tanks and wind tunnels. This resulted in the discovery of aerodynamic peak forces increasing to more than 200% of the normal peak forces and the average forces to be at least 125% of the normal average. These increases appeared to be caused by short-lasting periods of reversible stall. Recent wind-tunnel tests with a small wind turbine mimicking it's large-scale brothers/sisters showed that at low wind speeds the harvestable power can even be doubled with oscillating blades compared to stationary blades. This principle of Lift-Enhancing Periodic Stall (LEPS) has been filed in patent nr WO2017105244A1. Currently we are talking to wind industry partners to explore actual application in larger scale wind turbines.

Neurophysiological Characters Facilitate IR Imaging in Snakes

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Snakes in three taxa (boa, python and pit viper) possess two or more specific organs for sensing IR radiation with a sensitive arrange from 8 to 14 μm, peaked at 10μm, in wavelength. Although organ numbers in a snake are largely different among three taxa, the physical strait for IR imaging is much analogous, the big front opening of sensory organ. Because of relative low energy embedded in radiations with wavelength ¿ 1,200 nm, the large opening was evolved to absorb more radiation but to decrease significantly image resolutions. Our recent experiments of neurophysiological recordings in snake midbrains have revealed two important characters which would compensate consequently disadvantages of large opening in IR imaging. IR neurons in the midbrain were mostly responsive to the stimulus from a space-specific point, and each neuron seems to have its own spatial point. The stimuli came from areas surrounding the point induced much lower responses, suggesting some lateral inhibition projections. Two sensitive patterns in response to IR stimulations were found, e.g. heat sensor and cold sensor. The heat sensor was characterized by increasing its responsive amplitude with stimulating temperature increased while the cold one deceasing its responsibility when enhancing temperature. It is not clear yet if the heat and cold sensors distribute alternatively in the sensory membrane of the pit organ. We proposed that these two characters should be applied in design of IR imaging devices.

A Shadow Based Nano Scale Precision Force Sensor

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The meniscus surrounding a hydrophobic circular plate floating on a transparent liquid surface could refract light to form a shadow with a bright edge at the bottom of the vessel. This paper demonstrated the feasibility of a simple method to visually measure the force applied on the top surface of this circular plate by using its shadow image. The shadow area represented the floating force according to the updated Archimedes' Principle. The viscous damping of liquid could reduce the high frequency noises from the environmental vibration, which improved the stability and sensitivity of the measuring system. The water depth, initial weight of the plate, and the size of the circular plate effects on the shadows and the edge quality have been evaluated. With an ordinary camera to monitor the shadow, a simple circular plate device could realize a force resolution of up to 10 nN. The force measuring range and sensitivity can be easily extended by changing the radius of the circular plate. The shadow method could be developed into a novel nano scale precision force measurement apparatus.

Introduction to the International Society of Bionic Engineering

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Secretariat of International Society of Bionic Engineering, Changchun, 130012, China

The International Society of Bionic Engineering (ISBE) is an educational, non-profit, non-political organization formed in 2010 to foster the exchange of information on bionic engineering research, development and application. It is made up of over 2100 individual members and 20 corporate members come from 59 different countries and 6 continents of the world.

ISBE holds International Conference of Bionic Engineering (ICBE) every three years intending to bring together researchers and scholars in the academic field and industry from around the world to share their research experience and to explore research collaboration in the areas of bionic engineering. ISBE also organize other activities including workshops, seminars and symposiums to promote academic exchanges and cooperation.

The Transactions of the Society-the Journal of Bionic Engineering (JBE) is published by Springer and indexed by SCIE, the impact factor of which achieved 2.325 in 2017. ISBE offers information services via official website (http://www.isbe-online.org/), Newsletter, Wechat platform and Bionic Digital Library etc. The Society has gradually developed to be an influential international platform in the field of bionic engineering.

ISBE has collaborations with many international organizations and Institutions for academic communication. The organizations with which ISBE has significant collaborations are International Society for Terrain Vehicle Systems, American Society of Agricultural and Biological Engineers, Design Society, Korean Society of Mechanical Engineers, Point Loma Nazarene University, USA etc. The communication and cooperation on Bionics will surely promote the development of bionic engineering all over the world.

Kinematics of gecko climbing: the lateral undulation pattern

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Geckos are exceptional at terrestrial locomotion and capable of moving on diverse terrains and surface orientations. Here we studied the kinematics of lateral undulation pattern of geckos moving at various speeds on an inclined plane. An optical motion capture system was used to record eight G. geckos moving over a slope with velocity ranging from 0.47 - 7.66 SVL s-1 (Snout-Vent Length). Geckos employ the cyclical lateral bending of the flexible trunk to coordinate the limb movements and speed modulation to adapt the variation in locomotion velocities. The geckos increased both stride frequency and stride length to enhance motion speed however the effect of stride frequency on locomotion velocity was greater than that of the stride length. As the geckos? locomotion speed increased lateral frequency of the trunk also increased while lateral amplitude of the trunk remained nominally constant or even slightly reduced. Remarkably, gecko shows the transition from the standing wave to the traveling wave to adapt to the changes in speed. The waveform of the geckos? trunk appears as single-peak curves in the standing wave at low speeds and as serpenoid waves in the traveling wave at higher speeds. The phase relationship between body and limbs is maintained in phase in the standing wave, but diminished in the traveling wave condition. This transition likely reflects the presence of the central pattern generator (CPG) mechanism for the locomotion control in vertebrates with sprawling posture.

Energy-efficient, adaptive control of complex robotic movements

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Providing robots with the ability to learn and execute sequences of actions in an energy-efficient way demands a fast, adaptive, and power-saving control mechanism. In addition, with the currently ongoing robotic development, such as humanoid robots, more complex actions and higher cognitive processes (e.g., planning) need to be enabled and controlled. When learning a complex movement task, our nervous system self-organizes large groups of neurons into coherent dynamic activity patterns. During this, the neural network has to create multiple, computationally powerful cell assemblies – being strongly interconnected groups of neurons – each encoding a specific, complex part of the movement. Our theoretical investigations show how such ordered structures are formed in a self-organized manner by the interplay between homeostatic and synaptic plasticity. Interestingly, similar to liquid state machines, the internal dynamics within such a cell assembly enable the transformation of a multi-dimensional, time-dependent input to a specific multi-dimensional, time-dependent output encoding a desired arm movement. The desired movement has been demonstrated beforehand by a human to the robot enabling supervised (imitation) learning. Thus, the dynamic processes of synaptic and homeostatic plasticity results to the self-organized formation of cell assemblies each encoding a different action while preserving a rich diversity of neuronal dynamics needed for control. This type of self-organization provides a basic principle, which we currently transfer to Intel's neuromorphic chip "Loihi" to enable the control of complex movements of autonomous robots.

Bionic Hydrogels for Controlled Drug Release

Wei Zhang, Xin Jin, Heng Li, Chengxiong Wei, Chengwei Wu*

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Inspired by the multilayer structure of onion, we successfully develop the multilayer hydrogel capsules for inhibiting the burst release of drug by the ionotropic crosslinking method. Compared with monolayer hydrogel capsules, the multilayer hydrogel capsules can largely homogenize the distribution of drug and suppress drug concentration gradient between the outermost hydrogel layer and external environment, and the dense cuticular membranes can restrict the migration and dissipation of drug. As such, a significant inhibition of the burst release of drug can be achieved. Moreover, the bionic multilayer hydrogel capsules also demonstrate pH sensitive drug release behavior and good adhesion to cancer cell. The novel hydrogels have the potential for the applications in drug delivery system.

A Bio-inspired Wall-climbing Robot with Multi-locomotion Modes

Linsen Xu

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Wall-climbing robot is an essential branch of robotics, and the adhesive method is the key technology. Nowadays suction cups, magnets and grippers are three conventional modes for adhering. However, there are many limitations of these traditional methods, which makes it difficult for the wall-climbing robots to locomote under the complicated environments for special tasks. A novel wall-climbing locomotion mechanism can adapt multiple wall surfaces is brought out by imitating the special animals, such as geckoes or flies. It consists of the following five parts: a portable power supply module with high powered density, a driving system including two high precision brushless DC motors, a moving system adopting two adhesive belts on smooth wall surfaces and four spine wheels on rough wall surfaces, a switching system equipping with the tension spring structures to press four spine wheels on front and rear sides of the robot against wall surfaces in real time, and a negative pressure assistant system fabricated with a high-speed vortex fan. In the entire movement process, the robot realizes the acceleration, deceleration, turning, forward and reverse motion by employing logistic control program of two brushless DC motors. During climbing on the smooth surface, although the four spine wheels contact with the wall surface all the time, the robot's balancing force is mainly produced by the combined effect of the two adhesive belts and the high-speed vortex fan on account of the relatively small friction between the spine wheels and the wall surface. While climbing on the rough surface, the adhesive belts are gradually separated from the wall surface by controlling the fan speed to adjust the parameters relationship between the tension of the switching mechanism and suction of the negative pressure assistant system, then the robot's balancing force is mainly produced by the combined effect of the four spine wheels and the high-speed vortex fan. So the simple and effective switching mode enables the robot to be steerable and to transfer between various wall surfaces rapidly and stably. Moreover, based on the element stiffness matrix of the finite element method, an innovative mechanical model is set up to analyze the forces acting on multi-spines and the relation between adsorption force, gravity force and grasping force during a climbing cycle. Finally, the prototype of

the wall-climbing robot is manufactured and tested, and the experiment results show that the robot could climb stably on the multiple wall surfaces with a load of 0.5kg at a speed of 7 cm s_{-1}.

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Stress regulation at separating interface for bioinspired dry and wet adhesions

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In nature, several animal groups, like insects, arachnids, tree frogs, and lizards use reversible adhesions for their locomotion. Comprehensive studies have suggested two highly specialized structures, which are smooth pads and fibrillar pads, rather than the surface chemistry of the toe pads contribute mainly to the strong adhesion of those animals. While the direct contacts between fibrillar pads (like geckos and spiders) and solid surface generates van der Waals forces for the dry adhesion, the adhesion of smooth pad mediated with liquid at contact interface is considered as wet adhesion. Inspired by the amazing adhesion abilities of these animals, hierarchical micro- & nano-pillar arrays with various substructures have been developed. The presence of overhang structure on top of pillars and the rigid nanopillar inside soft smooth pad could alter the stress distribution between detaching surfaces and therefore contributes to the adhesion enhancement of artificial structures. Our research could pave the way to the new design of structured adhesives.

Research on humanoid robot: stable walking and intelligent manipulation

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Humanoids are machines that have the form and function of humans. The anthropomorphic form, which consists of bipedal legs, dual arms, hands, head and body, makes the robot be more acceptable in Human-Robot interaction and more adaptive to human's environments and tools, but also brings big challenges on the issues of stable movement due to its intrinsic instability characteristics, especially during fast and dynamic movement and under unknown external disturbance. Considering human's walking and running is not an all-hard work, soft tissues contributes lots to the stability as well as energy saving, we adopt the compliance torque/force control idea to research and develop the humanoid robot from the basic hardware design to the high-level planning and control algorithms. With the compliance idea, we develop a compact SEA for the legged joints, give the position and velocity control method for the SEA joint with the inner loop of torque control to keep it compliance and reduce the elastic influence on precision, design an elastic bionic leg with the coordination configurations learning from human, and propose the online dynamic model identification method, walking and running online adaptive planning method, and compliance balance method, etc. With these efforts, we developed a humanoid robot which can walking indoor and outdoor and be adaptive to the unknown disturbance. For anthropomorphic functions, perception, cognition, decision making and learning are also necessary. Aiming to make the humanoid robot intelligently manipulation, we researched on these technologies and developed two humanoid robots which can play table tennis with human players, even catch the fast spinning flying table tennis ball. Some technologies have been successfully applied to industrial applications.

A Shadow Based Nano Scale Precision Force Sensor

Tian Yu

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The meniscus surrounding a hydrophobic circular plate floating on a transparent liquid surface could refract light to form a shadow with a bright edge at the bottom of the vessel. This paper demonstrated the feasibility of a simple method to visually measure the force applied on the top surface of this circular plate by using its shadow image. The shadow area represented the floating force according to the updated Archimedes' Principle. The viscous damping of liquid could reduce the high frequency noises from the environmental vibration, which improved the stability and sensitivity of the measuring system. The water depth, initial weight of the plate, and the size of the circular plate effects on the shadows and the edge quality have been evaluated. With an ordinary camera to monitor the shadow, a simple circular plate device could realize a force resolution of up to 10 nN. The force measuring range and sensitivity can be easily extended by changing the radius of the circular plate. The shadow method could be developed into a novel nano scale precision force measurement apparatus.

A bioinspired surface fabricated by surface tension assisted replica molding for unidirectional Controllable liquid spreading

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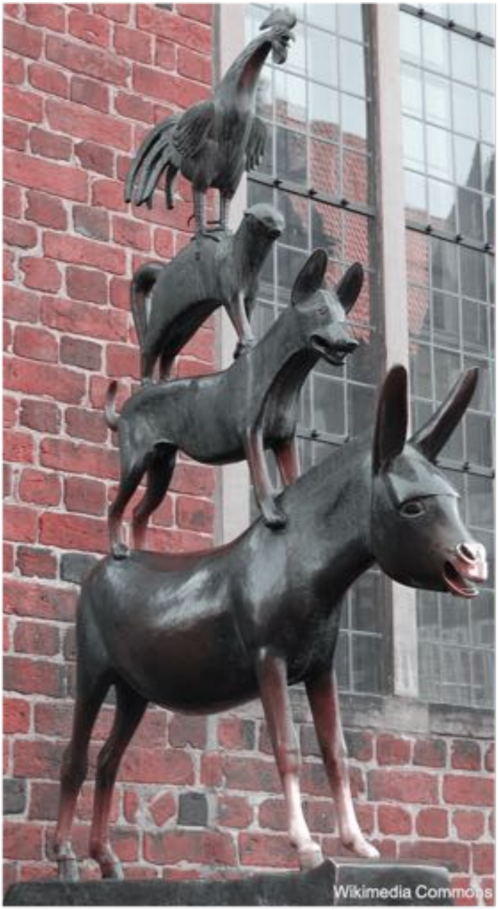
Uni-directional liquid spreading without energy input has attracted worldwide attention in recent years. Recently, a novel 2D uni-directional liquid spreading on the peristome of Nepenthes alata has been discovered, which is mainly as a result of its unique superhydrophilic hierarchical structure and duck-billed microcavities with arc-shaped edges and sharp wedge corners. In order to fabricate the peristome-inspired surface, the replica molding method is the highest efficiency and its structure is the most ideal. However, the curved shape of the final formed surface cannot be adjusted, which greatly limits its potential application. Here, we present a novel surface tension assisted replica molding method to fabricate an artificial peristome. The artificial peristome was fabricated by pouring the SBS dissolved by organic solvents into reverse templates which were made in PDMS based on the natural peristome. With the volatilization of organic solvent, the SBS particles form an artificial Nepenthes peristome under the surface tension. More importantly, the PDMS template swells in an organic solvent, and then return to the original size, which is conducive to the replication of microstructures. Besides, unidirectional water spreading speed on the artificial peristome can be dynamically regulated by stretching the artificial peristome. By investigating the relationship between liquid spreading speed and arc-shaped outlines, the underlying mechanism was revealed. This work gives a new way to achieve the control of unidirectional liquid spreading available for controllable microfluidics and medical devices.

Index of contributing authors



In the Brothers Grimm fairytale, the cat, the dog, the rooster and the donkey are on their way to Bremen. But before they reach their destination, they find a cottage in the woods and decide to stay. Nonetheless, the city considers itself to be the home of the would-be musicians and anyone acquainted with the story knows that the likeable quartet are honorary citizens of Bremen. Every year nearly 40 million people visit the famous statue at the town hall. Many more portrayals and statues of Bremen's favourite animals can be found in the city – in Böttcherstrasse, the Schnoor quarter and in Bürgerpark to name just a few. - Why not try to find them all?
Source: www.bremen-tourism.de