“The most creative conference in mechanism science”

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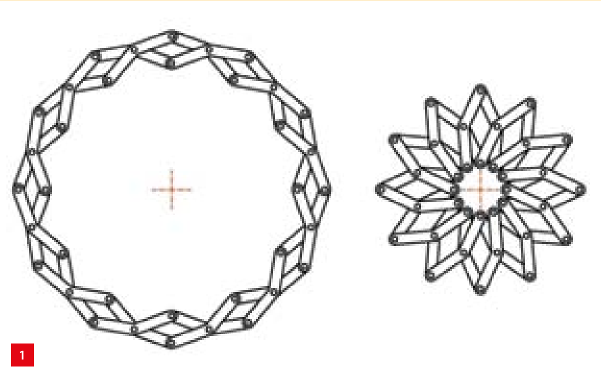
"THE MOST CREATIVE CONFERENCE IN MECHANISM SCIENCE"

A reconfigurable mechanism can be defined as a mechanism with changing mobility due to its specific mechanical design, for example changing from a configuration with one degree of freedom to a configuration with two degrees of freedom motion. Due to the practical and theoretical challenges of developing a reconfigurable mechanism and also because of the high variety of design possibilities, this topic pushes the designer to employ all of his or her creativity.

VOLKERT VAN DER WIJK AND JUST HERDER

Reconfigurable Mechanisms & Robots was the topic of the international IEEE/IFToMM conference ReMAR held at Delft University of Technology from 20 to 22 June 2018. It was the 4th edition of the conference which the organisers subtitled as "the most creative conference in mechanism science".

'Reconfigurable' can have a variety of meanings. A common explanation of a reconfigurable mechanism is a mechanism with changing mobility due to their specific mechanical design, for example changing from a configuration of one degree of freedom motion to a configuration of two degrees of freedom motion. This can be exploited by creating mechanisms with multiple operation modes that bridge the gap between machines, which are fast but can typically only perform one motion, and robots, which are not as fast but are highly flexible in that they can perform almost any motion within their reach. This is relevant at many length scales and applications ranging from cranes, kinetic art and robotics, to medical instruments and micro-devices.



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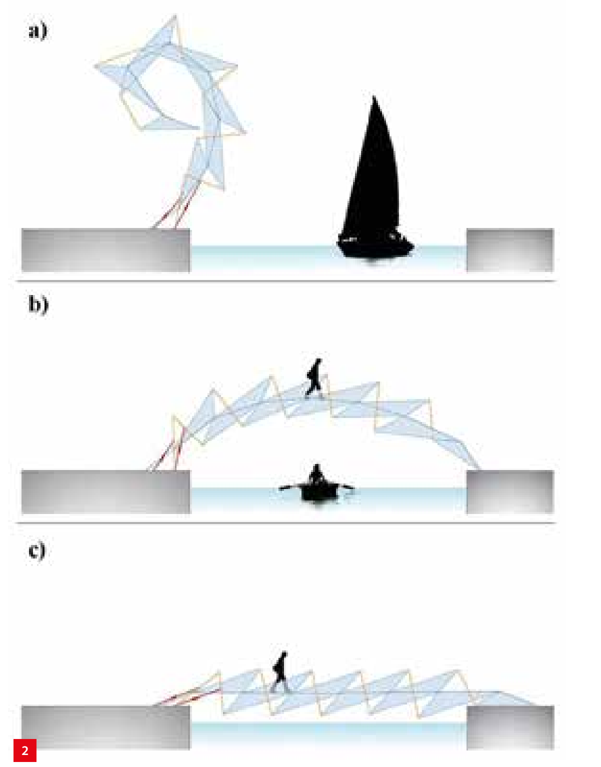
1 *A Hoberman Sphere [1].*



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2 *A deployable scissor-linkage bridge [2].*

AUTHORS' NOTE

The organisers of the ReMAR 2018 conference, Volkert van der Wijk (assistant professor) and Just Herder (professor), are associated with the Mechatronic System Design (MSD) research group of the Department of Precision and Microsystems Engineering at Delft University of Technology, the Netherlands.

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Scissor linkages

The conference showed the latest advances in this field, as well as related peculiar mechanisms. Keynote speaker Gökhan Kiper (IYTE Izmir, Turkey) gave an extended overview and classification of the design of scissor linkages. These linkages are the basis of a large range of deployable structures, i.e. structures that can be both folded compactly and deployed to span a large space. The Hoberman Sphere (Figure 1) is a well-known deployable toy consisting of such scissor linkages [1].

In his lecture, Kiper explained how scissor linkages can be generalised and how they can be better treated as scissor units, focusing not on the individual links but on the closed loops that two connecting scissor linkages form and use these loops as building blocks in the design. Concepts and prototypes of practical applications were illustrated, including deployable roof structures for portable emergency shelters and a bridge across the water which can deploy to open for boats and to close for pedestrians (Figure 2).

Architectured materials

Jonathan Hopkins (University of California, Los Angeles, USA) gave a keynote lecture on architectured materials, also referred to as mechanical metamaterials. These complex monolithic movable structures achieve properties that derive primarily from their microstructure instead of their material composition.
The microstructures of such materials typically consist of tiny compliant and often reconfigurable mechanisms that collectively work together within large lattices to produce extreme combinations of bulk super properties, which are not achievable by natural or synthetic homogenous materials.
Examples of such properties include engineered energy absorption and stress-wave propagation behaviours, extreme shape-reconfigurability, actively tuneable mechanical properties that can be programmed and uploaded wirelessly, and computational sensing achieved by mechanical-logic-inspired lattices.

Hopkins' lecture gave an overview of the design and fabrication tools that his Flexible Research Group has generated in the context of practical architectured-material applications. These design tools leverage the simplified mathematics of the Freedom and Constraint Topologies (FACT) [2] synthesis approach to rapidly search the full design space of both periodic and aperiodic architectured topologies to achieve desired combinations of properties. The group's fabrication tools utilise custom-developed components (e.g. a flexure-based micro-mirror array) to generate multiple optical traps that are independently controlled to assemble large numbers of different material micro-particles simultaneously for rapidly constructing desired microstructures.

The aim is to bridge the gap between the knowledge currently being generated in the field and the practical implementation of that knowledge for commercial applications. The two major advances required to bridge that gap include: dramatically improved design tools handling the infinite design space of microstructural solutions and new additive technologies that can fabricate practical volumes (> 1 m^3) of such lattices that often consist of multi-material true-3D submicron-sized features.

Kinetic art

To stimulate a creative atmosphere, the conference was opened with a keynote lecture by Delft-based kinetic artist Theo Jansen. He explained and demonstrated how reconfigurability is at the core of the designs of his 'strandbeesten' (beach animals): large walking creatures made of yellow electricity tubing, which use wind as energy source to live on beaches.

For instance, the self-propelling beach animal Animaris Percipiere uses a 'stomach' of recycled plastic bottles that contain air to store energy. They are pumped to a high pressure by the wind and the animal's wings. This air is used by artificial muscles to drive and control the animal. The muscles act as a kind of piston which can open taps to activate other muscles that open other taps, and so on. This creates control centres which can be compared to brains.

After explaining how he obtained the exact design of his world famous strandbeest leg in the late 1980s with the aid of genetic algorithms, Jansen demonstrated the muscles and the brain communication by means of the mechanical nerves (Figure 3). With these devices the beach animals can, for instance, communicate, sense, react to water by walking away from it, and attach themselves securely to the sand when the wind becomes too strong.

WWW.STRANDBEEST.COM


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3 *Theo Jansen (left), assisted by conference co-organiser Just Herder, demonstrating the strandbeest's artificial muscles and brain communication by means of the mechanical nerves.*

Soft robots

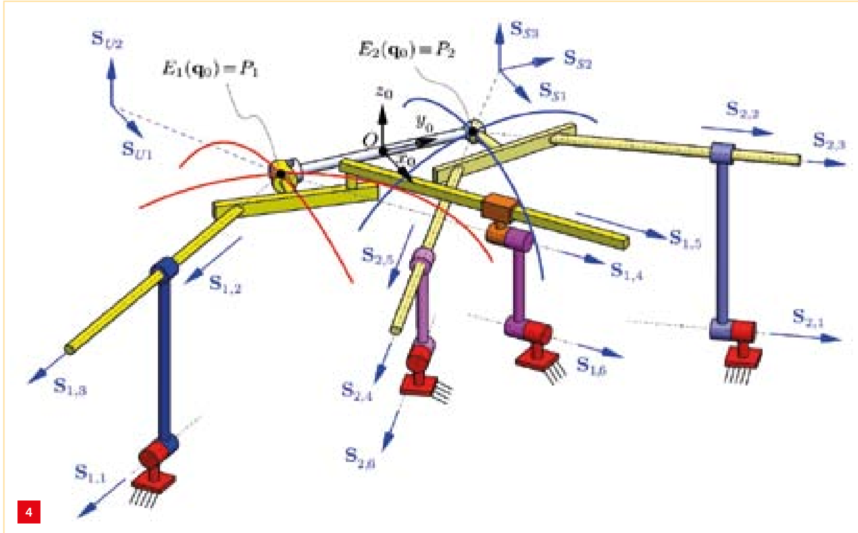
The keynote lecture of Metin Sitti (Max-Planck Institute for Intelligent Systems, Stuttgart, Germany) was all about reconfigurable mechatronics applied for micro-biorobotics. He presented their recent activities on design, manufacturing, and control of new shape-programmable untethered soft robots at the milli/microscale. These are based on soft functional active materials that can enable physical intelligence for small-scale (from a few millimeters down to a few micrometers overall size) devices and robots by providing them with unique capabilities, such as shape changing and programming, physical adaptation, and multi-functional and drastically diverse dynamics.

First, a computational design and fabrication method to create 2D shape-programmable magnetic soft elastomers was shown that can generate the desired large number of shapes using a programmed non-homogeneous magnetisation profile and uniform magnetic field control input. Using such methodology, a grand challenge in small-scale mobile robotics was addressed: how to navigate mobile robots in complex environments with multiple terrains (e.g. on solid surfaces, inside fluids, at the fluid-air interfaces) using multiple locomotion modalities like animals in nature? An example was shown doing undulatory swimming, jellyfish-like swimming, water meniscus climbing, jumping, ground walking, rolling, and crawling to navigate in a complex environment, such as inside the human body. One of the interesting potential applications shown was the ultrasound-guided navigation of such a soft robot inside ex-vivo chicken tissue towards their medical applications to deliver drugs and genes locally, and heat the local tissues for hyperthermia and cauterisation.

Auxetic behaviour

During the conference four awards were presented. The best theoretical paper award was for the research by Ciprian Borcea and Ileana Streinu on a longstanding open problem in auxetics. Where most materials become laterally thinner when stretched, auxetic behaviour is the opposite with lateral widening upon stretching, a property often studied in meta-materials. A theoretical understanding of the role of geometry in auxetic behaviour has been a challenge for a long time.

They showed that for structures modelled as periodic bar-and-joint frameworks, including atom-and-bond frameworks in crystalline materials, there is a complete geometric solution, opening endless possibilities for new auxetic designs. They constructed a large family of three-dimensional auxetic periodic mechanisms and discussed the ideas involved in their design.



4 *The double-Koenigs mechanism, a completely new reconfigurable spatial linkage [4].*

Spatial linkage

The award for the best student paper was given for the research by Pablo López-Custodio, et al. who presented a completely new reconfigurable spatial linkage (see Figure 4) with cusp singularities and multiple branches of motion, referring to it as the double-Koenigs mechanism. The white bar with point O is the reconfigurable end effector of the manipulator. This bar is connected with the couplers of two Koenigs joints, which are in fact closed-loop linkages.
The Koenigs joint is known as a constant-velocity shaft coupling that allows transmission of rotation between two non-collinear axes at a rate of 1:1, but here the Koenigs joint was generalised to have spatial motion with links of unequal lengths. The local mobility and singularity

Conference wrap-up

Around 105 participants from 25 countries in five continents participated in the ReMAR 2018 conference. Sixty papers were accepted after peer review and will be published in IEEE Xplore. All the authors presented their work in a three-minute podium pitch and a 90-minute interactive session, which was an excellent combination for showing and discussing the research with prototype models, demonstrators, videos and posters in a relaxed setting.

The conference site was within the TU Delft Mechanical, Maritime and Materials Engineering faculty building, which allowed all participants to feel the vibe of the first-year mechanical engineering students who at exactly the same time were testing and presenting their machines for the annual mechanical engineering design contest. The social activities, namely the welcome reception at the historic city hall and the canal boat trip to the conference dinner in the Old Church, were also well received.

The next (5th) conference on Reconfigurable Robots & Mechanisms will be in Toronto, Canada, in 2021.

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analysis of this complex mechanism showed to be a challenging problem for which common methods proved inadequate.

Origami

The best application award was given to Todd G. Nelson, et al. for their research on the implementation of rolling contacts for the so-called synchronised-offset-rolling-contact element (SORCE) joints. These joints were developed for thickness accommodation in origami-inspired mechanisms, combining selected strengths of several thickness-accommodation techniques, but with the trade-off of manufacturing complexity of rolling joints. Principles to facilitate the construction of rolling joints suitable for applications like the SORCE technique were presented. These include leveraging fold-angle multipliers of origami vertices, variations of flexure assembly, sunken flexures, and form-closed rolling joints. Prototypes of origami mechanisms using the SORCE technique were constructed and shown to demonstrate these principles. The technique is also well suited for use in other areas where rolling joints are beneficial due to their unique qualities of a moving axis and low friction.

Additional degrees of freedom

The most creative presentation award was given to Abhilash Nayak, et al. for presenting their work on a dual reconfigurable 4-rRUU parallel manipulator. This is a manipulator where the moving platform is connected to the base by four kinematic chains or 'limbs' with revolute and universal joints. They showed how they used a double Hooke's joint linkage to reconfigure the base revolute joints of a 4-RUU parallel manipulator whose platform motion then depends on the angle between the driving and the driven shafts of the double Hooke's joint linkage in each limb. With this construction the rotational input motions of the shafts of the fixed motors are changed into another direction such that each limb obtains a variable orientation of the base R-joint. Due to the additional degrees of freedom the resulting 4-rRUU parallel manipulator can move into a variety of operational modes. This was wonderfully demonstrated by a prototype, videos, pictures, and simulations. ■

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