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Biomimetic and Biohybrid Systems

9th International Conference, Living Machines 2020
Freiburg, Germany, July 28–30, 2020
Proceedings

Springer

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ISSN 0302-9743 ISSN 1611-3349 (electronic)
Lecture Notes in Artificial Intelligence
ISBN 978-3-030-64312-6 ISBN 978-3-030-64313-3 (eBook)
https://doi.org/10.1007/978-3-030-64313-3

LNCS Sublibrary: SL7 – Artificial Intelligence

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

These proceedings contain the papers presented at the 9th International Conference on Biomimetic and Biohybrid Systems (Living Machines 2020), held online during July 28–30, 2020. The international conferences in the Living Machines series are targeted at the intersection of research on novel life-like technologies inspired by the scientific investigation of biological systems, *biomimetics*, and research that seeks to interface biological and artificial systems to create biohybrid systems. The conference aim is to highlight the most exciting international research in both of these fields united by the theme of "Living Machines."

The Living Machines conference series was first organized by the Convergent Science Network (CSN) of biomimetic and biohybrid systems to provide a focal point for the gathering of world-leading researchers and the presentation and discussion of cutting-edge research in this rapidly emerging field. The modern definition of biomimetics is the development of novel technologies through the distillation of principles from the study of biological systems. The investigation of biomimetic systems can serve two complementary goals. First, a suitably designed and configured biomimetic artifact can be used to test theories about the natural system of interest. Second, biomimetic technologies can provide useful, elegant, and efficient solutions to unsolved challenges in science and engineering. Biohybrid systems are formed by combining at least one biological component – an existing living system – and at least one artificial, newly engineered component. Through passing information in one or both directions, such a system forms a new hybrid bio-artificial entity.

The abiding desire to imitate the functionality of living organisms dates back hundreds of years. Early examples of biomimetic artifacts can be found as early as 400BC, by Archytas, an ancient Greek philosopher. He was the creator of "the first autonomous volatile machine of antiquity," namely the Flying Pigeon. This device was one of the first studies on how birds fly. Its structure resembled that of a bird with a pointed front, similar to a bird's beak, and its aerodynamic shape and mechanisms allowed the Pigeon to fly for approximately 200 meters. Centuries later, around the European Renaissance, we observe endeavors that explore the reproduction of aspects of living organisms in machines, while revealing important information regarding their nature. Leonardo da Vinci is a great example of linking human kinesiology and anatomy with his "Knight" in 1495, while his study of birds resulted in numerous sketches of various flying machines.

What initially started as a philosophical idea turned into a mechanical revolution. Already during the 18th century, machines not only imitated the external appearance of an organism but also simulated its functionalities of behaviors. A way to appreciate the early simulation of living beings is the central idea of "moving anatomy" in the creations of Jacques de Vaucanson (1709–1782), a French inventor and artist. His mechanical artifacts (like the "Flute Player" or the "Digesting Duck") intended to approximate the anatomical, physiological, and behavioral characteristics of their

biological counterparts. The tendency of this period to use machines that resemble nature climaxed with the creations of Pierre Jaquet-Droz (1721–1790) that later constituted the basis for constructing prosthetic limbs.

Nowadays, the study and modeling of biological systems has led to the acquisition of insights into a plethora of domains ranging from architecture to materials, sensors, and control systems, and even robotics. The Velcro is an example of a fastening system inspired by the tiny hooks found in the surface of burs. The leaves of the lotus plant have inspired the creators of umbrellas and hydrophobic paints and coatings. Hypodermic needles were inspired by observing how snakes deliver poison through their fangs. Japan's bullet trains were remodeled after the Kingfisher's beak to reduce air resistance and boom sounds, while at the same time the trains now travel 10% faster and use 15% less energy. The Eastgate Centre, a shopping mall and office space in Zimbabwe, whose ventilation and cooling system was done entirely by natural means, was inspired by the self-cooling mounds of African termites. These remarkable advances are only some of the many examples that biomimetic approaches have to offer, and several new approaches were presented in the Living Machines conference.

The main conference took the form of a two-day single-track oral and poster presentation program that included four plenary lectures from leading international researchers in biomimetic and biohybrid systems: Auke Ijspeert (Swiss Federal Institute of Technology in Lausanne, Switzerland) on animal locomotion and biorobots; Bas Overvelde (Soft Robotic Matter group, The Netherlands) on adaptive and modular soft robotic systems; Li Zhaoping (Max Planck Institute, Germany) on visual systems in humans, animals, and machines; and Holk Cruse (Bielefeld University, Germany) on insect-inspired hexapod controllers. There were also 12 regular talks and 2 poster spotlights featuring 29 posters. Session themes included: collective and emergent behaviors in animals and robots; biomimetic vision and control; insect-inspired robotic systems; advances in soft robotics; and biomimetic and biohybrid systems.

The conference was complemented by two online workshops. More specifically, the "Growing structures: bioinspired innovation insights for architecture and robotics" workshop was organized by Barbara Mazzolai, Thomas Speck, and Mirko Kovac. Cross-disciplinary talks in this workshop showed current initiatives and major perspectives on the form-structure-function-relationship on various hierarchical levels of biological materials and structural systems; growing and building strategies in plants and animals; plant-inspired technologies for adaptable and growing robots; as well as biomimetic and biorobotics architectural installations and buildings. The "Shared workspace between humans and robots" workshop was organized by Apostolos Axenopoulos, Dimitrios Giakoumis, Eva Salgado, Vicky Vouloutsi, and Anna Mura. The aim of this workshop was to present and discuss together with scientific and industrial stakeholders' novel technological approaches that facilitate the collaboration between robots and humans towards solving challenging tasks in a shared working space without fences.

The Living Machines conference traditionally chooses historical and inspirational venues at the crossroads between life and human sciences. This year the conference was to take place at the Botanical Garden of Freiburg. However, the world is crossing uncharted territory as it faces the COVID-19 pandemic. This outbreak is having a significant impact on our life, health, and economy as more than 20 million people have

been affected. COVID-19 also has an impact on how our society communicates, and the scientific communities are also affected by this terrible pandemic. To act in complete observance of safety and ethical practices, and to maintain the scientific research and knowledge exchange with new lockdown-proof methods and technologies, the conference this year was held online. The conference was hosted by the Cluster of Excellence at the University of Freiburg, Germany, and by the "Living, Adaptive and Energy-autonomous Materials Systems (livMatS)" (www.livmats.uni-freiburg.de). The workshops were hosted by the Cluster of Excellence at the University of Freiburg. The great success of the first virtual edition of the conference follows previous successful editions in Nara, Japan in 2019; Paris, France in 2018; Stanford, USA in 2017; Edinburgh, UK in 2016; Barcelona, Spain in 2015; Milan, Italy in 2014; London, UK in 2013; and Barcelona, Spain in 2012.

We would like to thank our hosts for the conference, workshops, and poster sessions held at the Cluster of Excellence at the University of Freiburg and livMatS.

We also wish to thank the many people that were involved in making the 9th edition of Living Machines possible: Thomas Speck and Paul Verschure co-chaired the meeting; Vasiliki Vouloutsi chaired the Program Committee and edited the conference proceedings; Tony Prescott chaired the international Steering Committee; and Anna Mura was the general organization chair and also coordinated the Web and communications. Thomas Speck and his group, including Falk Tauber and Sonja Seidel, provided local organizational support. We are grateful to the SPECS lab at the Institute for Bioengineering of Catalonia (IBEC) in Barcelona for the assistance in the organization and technical support. We would also like to thank the authors and speakers who contributed their work, and the members of the Program Committee for their detailed and considered reviews. We are grateful to the four keynote speakers who shared with us their vision of the future.

Finally, we wish to thank the organizers and sponsors of Living Machines 2020: the SPECS-lab at Institute for Bioengineering of Catalonia IBEC, the Catalan Institution for Research and Advanced Studies (ICREA), and the University of Freiburg. Additional support was also provided by Springer. Living Machines 2020 was also supported by Sensors and the IOP Physics journal *Bioinspiration & Biomimetics*, which will publish a special issue of articles based on the best conference papers. The Biomimetics - Open Access Journal, livMatS, microTEC Südwest, 3D Bio-Net, and GrowBot awarded the first and second best papers and posters.

July 2020

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