robosoft 2021

Workshop

Plant-hybrid machines, sensors, energy systems – an interface for soft robotics?

SCHEDULE (NY TIMEZONE)	
9:00 – 9:30	**Fabian Meder/Barbara Mazzolai** Bioinspired Soft Robotics, Istituto Italiano di Technologia, Italy **Prologue to the workshop, plant-inspired soft robotics, and plant-hybrid energy systems**
9:30 – 10:00	**Thomas Speck** Plant Biomechanics Group, University of Freiburg, Germany **Plant movements as concept generators for bioinspired motion and actuation in soft machines**
10:00 – 10:30	**Trisha L. Andrew** Wearable Electronics Lab, University of Massachusetts, Amherst, USA **Transforming Live Plants into Sensors and Living Sensing Systems**
10:30 – 11:00	***Break***
11:00 – 11:30	**Zhigang Wu** State Key Laboratory of Digital Manufacturing Equipment and Technology, Huazhong University of Science and Technology, China **Physiology Monitoring and Growth Manipulation for Tender Plants Using Hydroprinted Dynamic Morphing Electronics**
11:30 – 12:00	**Juan Pablo Giraldo** Department of Botany and Plant Sciences, University of California, USA **Turning plants into environmental sensing technology through nanoscale engineering**
12:00 – 12:30	**SHORT TALKS** ***Adaptive biomimetic actuator systems for a compliant foil based artificial Venus flytrap demonstrator combining two biological snap-trap mechanics*** **Falk Tauber**, Philipp Auth, Joscha Teichmann, Thomas Speck ***Electrical Plant Physiology Using Bioimpedance Spectroscopy and Analysis*** **Jae Joon Kim**, Trisha L. Andrew ***The biomimetic cellular actuator – learning from leaf movements triggered by bulliform cells*** **Olga Speck**, Anja Mader, Max Langer, Jan Knippers ***Towards energy harvesting using falling rain drops using living plants as energy converters*** **Serena Armiento**, Fabian Meder, Barbara Mazzolai
12:30 – 13:30	***Break***
13:30 – 14:00	**Eleni Stavrinidou** Laboratory of Organic Electronics, Linköping University, Sweden **Plant based biohybrid systems**
14:00 – 14:30	**Muhammad M. Hussain** Electrical Engineeering and Computer Science, University of California, USA **AI Enabled UAV for Massive Deployment of Flexible High Performance Electronics for Enhanced Agricultural Productivity**
14:30 – 15:00	**Open discussion, workshop conclusions**

Organizers and Invited Speakers

Fabian Meder and Barbara Mazzolai
Bioinspired Soft Robotics, Istituto Italiano di Technologia, Italy
Prologue to the workshop, plant-inspired soft robotics, and plant-hybrid energy systems

Abstract

Welcome and introduction to the workshop. We will give an overview on plants' exciting solutions for soft robotic systems. Taking inspiration from unique plant properties like growth, exceptional adaptation, and intrinsic sensing capabilities and translating them into the field of robotics, provides the opportunity to derive and expand solutions for existing and totally new robotic applications that we translated into the first self-growing and adapting plant-inspired robots. Moreover, we show that plant-hybrid devices consisting of living plants combined with artificial soft electronics components can be used to convert mechanical energy into electricity sufficient to power external commercial electronic devices interfaced with the plant. Therefore, we make use of a recently revealed plant intrinsic energy conversion mechanism given by the cuticle-cellular tissue bilayer capable to convert mechanical excitation on the leaf surface into electricity based on coupling of contact electrification of the plants outermost surface and electrostatic induction in the cellular tissue, fully enabled by the plant intrinsic structure. By creating artificial leaves and constraining them to natural leaves on whole plants, the overall efficiency increases and wind energy can be converted into electricity. The plant hybrid generators can produce electricity even at low wind speeds and power a sensor circuit and LED light bulbs. Such plant-hybrid systems can be further engineered to provide a potential autonomous and green energy source for sensing applications.

Thomas Speck
Plant Biomechanics Group, University of Freiburg, Germany
Plant movements as concept generators for bioinspired motion and actuation in soft machines

Abstract

Plant movements and the structures involved differ in many aspects from those in animals. Important differences are the mode of actuation – plants have no muscles – and the structure of connecting regions between elements moving against each other – plants have no localized hinges with gliding parts. This makes plant movements interesting concept generators for kinematics of soft machines as they offer widely unexplored and often surprising solutions for structuring the connecting regions and for the mode of actuation. A general pattern found in most inherently mobile plant organs is elastic deformation, i.e. the distribution of deformation required for movement over a larger region and by this the avoidance of localized stress and strain concentrations. Modes of actuation comprise typically slow hydraulic processes (i.e., water displacement processes between cells and tissues) based on the consumption of metabolic energy, as well as hygroscopically actuated motions driven by changes in environmental humidity independent of metabolic energy. Both processes may be sped up by releasing embodied energy stored in the mobile structures. Presented examples for the transfer to biomimetic soft machines include intertwined searcher stems of lianas for growing soft robots, hygroscopically actuated flaps for building envelopes and pneumatic actuators and grippers for handling assistants.

Trisha L. Andrew
Wearable Electronics Lab, University of Massachusetts, Amherst, USA
Transforming Live Plants into Sensors and Living Sensing Systems

Abstract

Vapor-printed conducting polymer tattoos on the leaves of living plants can be used to perform on-site impedance analysis, which accurately probes the health of actively-growing specimens. Vapor-printed polymer electrodes, unlike their adhesive thin-film counterparts, do not delaminate from microtextured living surfaces as the organism matures and do not observably attenuate the natural growth pattern and self-sustenance of the plants investigated thus far. On-demand, noninvasive bioimpedance spectroscopy performed using reporter plants systematically placed in mid-sized farms and orchards can reliably detect multi-systemic or deep tissue damage caused by common stressors, such as dehydration, UVAexposure and overfertilization throughout the life cycle of a plant.

Zhigang Wu
State Key Laboratory of Digital Manufacturing Equipment and Technology, Huazhong University of Science and Technology, China
Physiology Monitoring and Growth Manipulation for Tender Plants Using Hydroprinted Dynamic Morphing Electronics

Abstract

Emerging epidermal electronics that can conveniently acquire vital signals of living organisms exhibits high potential for applications on plants. But it is still a significant challenge to interface the fascinating functions of inorganic electronics with plants, because plant organisms are fragile and can change significantly during growth. Using a gentle non-invasive process of hydroprinting liquid alloy circuit, we have developed an intrinsically plant morphing electronics that can adapt to this highly dynamic situation without introducing any external interventions such as heat flow, pressure, acid or base. Functional liquid alloy circuits with morphing ability can be conformably transferred onto the 3D fragile micro-structured surfaces of plants. Due to the excellent compliance, deformability and functionality of liquid alloy, such dynamic morphing electronics function well on the epidermis of fast-growing (up to 2.3 mm/h) plants for various applications including monitoring leaf moisture content and length, and growth manipulating. This study lays the foundation for a new form of morphing electronics for botany or bio-hybrid plant robots, potentially impacting the next generation of precision agriculture and smart hybrid robots.

Juan Pablo Giraldo
Department of Botany and Plant Sciences, University of California, USA
Turning plants into environmental sensing technology through nanoscale engineering

Abstract

Plants have traditionally been used as sources of oxygen, food, fuel, and materials. Recently, nanomaterials' distinct optical, electronic, mechanical and chemical properties are enabling the use of plants as novel technologies including environmental sensing, energy harvesting and conversion devices. For example, carbon nanotube-based sensors embedded in leaves can turn plants into groundwater analyte sensors or plant health sentinels that communicate with electronic devices, and nanomaterial-protein complexes have allowed engineering of light emitting plants and the creation of self-repairing materials. Plants have colonized diverse, extreme, and remote ecosystems in which autonomous functioning of electronic devices is challenging. Plant's self-powered, self-repairing properties and high sensitivity to their surroundings offers a hybrid organic chassis for nanobiotechnology-based monitoring devices. However, a main limitation for engineering plants as technological devices is our understanding of the underlying mechanisms of how nanoparticle properties control their spatial distribution and transformation in plants. Systematic experimental and modelling studies of nanoparticle-leaf interactions based on nanomaterial chemical and physical properties are crucial for identifying targeted approaches that interface nanomaterials more precisely and efficiently with plant cells and organelles. Merging the unique properties of nanoscale materials with plants can lead to platforms that replace environmental sensing devices made of plastic, circuit boards, and require an electrical power grid.

Eleni Stavrinidou
Laboratory of Organic Electronics, Linköping University, Sweden
Plant based biohybrid systems

Abstract

Plants convert solar energy to chemical energy, sequester carbon, sample the environment and synthesize a variety of materials. Augmenting functionalities to plants with smart materials and devices can result to biohybrid systems for energy harvesting, environmental monitoring and in-vivo biofabrication. Recently we demonstrated a conjugated oligomer that was uptaken by the vascular tissue of the plant and in vivo polymerized forming conductors. The thiophene-based molecule polymerized within the living tissue, without external chemical or physical stimuli only due to the physiochemical environment of the plant. We used the biohybrid system for energy storage. Currently we are functionalizing rooted plants forming conductors in parallel with the growth of the plant, with the conjugated polymer integrating into the plant cell wall. Here I will present the underlying mechanism of the polymerization. We show that the polymerization is driven from the defense mechanism of the plant through enzymes that are involved in modulating cell wall density. With in-vitro and in-vivo studies we identify the key components, limiting factors and kinetics of the polymerization reaction. This work paves the way for rational design of materials for plant functionalization and advance biohybrid systems.

Muhammad M. Hussain
Electrical Engineeering and Computer Science, University of California, USA
AI Enabled UAV for Massive Deployment of Flexible High Performance Electronics for Enhanced Agricultural Productivity

Abstract

Electronics technology has enabled an era of computation-communication-infotainment. Going forward, by redesigning such high performance electronics can be used for soft-interfacing with biology. Specifically with the emergence of Internet of Everything, where people-process-device-data will be seamlessly connected, we are eager to know how nature works, how we can mimic them, how we can interface them more and more importantly how we can augment the quality of our life?
To address these important questions, inspired by nature, we are redesigning conventional CMOS electronics into physically fully compliant electronics to redefine their purposes. We integrate heterogeneous materials (classical crystalline and novel 1D/2D) and processes (state-of-the-art CMOS technology and emerging processes) through robust manufacturable processes to develop physically flexible, stretchable and reconfigurable standalone biocompatible CMOS electronic system. We are gradually using machine learning to incorporate AI and robotics into these electronic eco systems to make them interactive – without any human interface. An example will be shared: an array of butterfly like

sensors to monitor plant growth. They are deployed through AI enabled UAVs without any human intervention.