Open Labware for plant electrophysiology

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The Idea

Our idea is to develop an affordable, open source, hardware-software "sandbox" to allow plant scientists to explore the possibilities of in-vivo experimentation with plant electrophysiology. We plan to build on the existing Plant SpikerShield* system, which consists of electrodes (positioned on the plant by means of a 3d printed "manipulator") whose signal is amplified by a custom made electronic circuit which then is sent to a computer via an Arduino microcontroller. The data can then be recorded, plotted and analysed. Specifically, we seek to replicate this system, enhance its mechanical setup and develop a robust open source high-level graphical user interface for data recording and analysis in any given platform (Window, OSX, Linux) using browser capabilties, Jupyter and Javascript. Our enhancements to this system will be designed with the plant sciences community in mind, with an emphasis on user-friendly design, realistic scalability and portability. These features will also enable outreach to other communities, for example in educational settings.

We will also create a set of easy to reproduce experiments, focusing on model systems such as Marchantia and Arabidopsis. We will emphasise two aspects:

1. The coupling of plant signaling with external electrical circuits to facilitate study of phenomena such as the emergence of synchronisation, resonance, chaos and other common collective effects observed in networks of excitable media. This will be of interest not only to plant sciences, but also in other fields of science, e.g. physics, engineering and mathematics.
2. The triggering and manipulation of behaviours in artificially coupled circuits of plants.

Our longer term aim behind creating these experiments, developing a plant-sciences friendly user-interface and enhancing the Plant SpikerShield set-up is the development of a gold-standard system to study oscillations in biological networks.

*Plant SpikerShield, Backyard Brains

Who We Are

Our team is composed by physicists, biologists and bioinformaticians.
The main part of the proposed work will be carried out by:

Dr. Carlos A. Lugo, which is a postdoctoral researcher in the bioinformatics group in The Sainsbury Laboratory, Norwich, U.K. his background is that of Physics and Systems Biology.
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and
Dr. Marco Aita, which is a University of Cambridge/Wellcome Trust Senior Internship for Interdisciplinary Research Fellow. working in developmental aspects of plants in the Sainsbury Laboratory, Cambridge. U.K. his background is physics and plant mechanics.
e-mail: marco.aita@slcu.cam.ac.uk

The work related with the second part if the project, once the system is completed and in full use will involve Mr Christian R. Boehm, who is a PhD student in Plant Sciences at Haselhoff's Lab in the university of Cambridge (e-mail: crb59@cam.ac.uk) and Mr Guru Vighnesh Radhakrishnan who is a PhD Student, at the John Innes Centre in Prof. Giles Oldroy's group. Both would be involved in assisting the performance of experiments using the system Marchantia, which is already available at TSL-JIC sites. Guru's bacjground is Cell and Developmental Biology (e-mail: guru.radhakrishnan@jic.ac.uk)

The in-silico and theoretical knowlegde of pathways and Ca2+ channels involved in Marchantia is provided by Prof. Richard Morris, from JIC, who is the head of Computational and Systems Biology, and will act as an advisor at the minute of designing some of the proposed experiments. (e-mail: richard.morris@jic.ac.uk)

Finally, at last but not least, backend and front end develop of some of the software and data collection and classification will be in charge of Dr Marielle Vigouroux, whose background is Bioinformatics and Computational Biology, she is based at the John Innes Centre
Implementation

Aim: Test and Enhance Plant SpikerShield System Hardware
Methods: We will acquire, build and a Plant SpikerShield bundle (https://backyardbrains.com/products/plantspikershield). We will test the mechanics, electronics and data-stream implementation in order to determine if it requires modifications.
The mechanics of the system are available as 3D files ready to be printed, so if modifications are required, these can be easily implemented. Of particular interest is to add at least one high precision servo-mechanism to remotely control the electrode positioning system. All modifications will be documented in a GitHub repository, in principle this could be included within the existing Open Labware project.

People: Carlos Lugo and Marco Aita – build, test and refine system

Aim: Test and Enhance Plant SpikerShield System Software
Methods: We will test the code provided (Arduino interface and processing) and perform any modification necessary. To control the servo mechanisms we will add an extra Arduino micro-controller to the system. We will write the code for this using Gobot or Cylonjs APIs (http://gobot.io/, http://cylonjs.com/). All modifications will be documented in a GitHub repository, in principle this could be included within the existing Open Labware project.

People: Carlos Lugo – coding, and curation of repositories

Aim: Create High-Level Graphical User Interface (GUI)
Methods: We will wrap the respective Arduino API, so it can function as the back-end of an intuitive browser-based front-end application.

People: Carlos Lugo – back-end coding; Marielle Vigouroux – front-end coding

Aim: Creation of Experimental Set-Ups
Methods: We will buy/grow model plants and study these with our enhanced SpikerSystem. We will begin by characterising the response of single plants to diverse stimuli (e.g. light,

temperature). Results will be used to develop simple in-silico models which will then allow us to devise interesting collective scenarios for artificially connected circuits of plants.
Experimental protocols will be made freely available on-line in a range of media, e.g. GitHub, YouTube, OpenPlant Website.

People: Richard Morris – experimental design; Guru Vighnesh Radhakrishnan and Christian Boehm: – Marchantia expert advisors and growers; Carlos Lugo and Marco Aita – design and implementation of experiments.

Benefits and outcomes

The outcomes and benefits of this project will be:
1. An open-source, labware sandbox designed to encourage innovations in the study of plant electrophysiology. The system will be hi-tech yet affordable and have a high degree of useability without requiring extensive knowledge of programming.
2. Comprehensive but accessible supporting documentation for the above.
3. At least two exciting new experimental designs which could be further explored within the framework of synthetic biology. This has potential to provide a gold-standard system to study synchronisation and oscillations in biological networks.
4. Establishment of new interactions between researchers working in Cambridge and Norwich. This includes contact between The Sainsbury Laboratory Bioinformatics Group (Norwich; Lugo), Sainsbury Laboratory (Cambridge; Aita), University of Cambridge Plant Sciences (Cambridge; Boehm), and John Innes Centre (Norwich; Radhakrishnan, Morris and Vigouroux). This group is composed of scientists from diverse disciplines (bioinformatics, experimental and theoretical physics, biology) and career stages (from experienced Professor to PhD student).

Budget

Budget:
2 Plant SpikerShield to be cloned.
2 x 154.65 pounds= £ 309.3
Includes:
Plant SpikerShield amplifier
Arduino
The 3d printed manipulator.
1 electrode
1 Metal table
Electrode gel.
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2 X Behringer UCA222 U-Control Ultra-Low Latency 2 In/2 Out USB Audio Interface (To use as a transducer, in the hacked versions)
2x £23.72= 47.44
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Arduino UNO Starter kit
3 X 44.28=132.84
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Electronic Components to clone 3 Spiker Circuit and Non-linear 5 RLC oscillators.
3 x 40.75=122.25 (Electrode Materials, Resistor, switches, Capacitors and Operational Amplifiers: AD623N, TLC2272)
5 x 40=£90
3 Stepper/Servo Motors + Drive Systems: £ 250

3d printing filament = £45 (3 X £15)
3 ECG Gel SixPacks= 3 x £15= £45
Nuts and Bolts + Soldering Kit + Circuit PCB printing= £50
Plants (start Venus Flytrap, GM-Marchantia) £50
6 Cambridge-Norwich Trains plus other transport £240+ £60=£300

We should be using the resources of Makespace in Cambridge, and both Sainsbury laboratories to carry out experiments.
1 Arduino Mega +Arduino Mega Shield + Cases and USB cables = £150

Total=1581.83