Open Pi-Image: A low cost-open source plant growth imaging and analysis platform

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The Idea

Image capture and analysis is a cornerstone of many aspects of plant science, including the study of developmental morphodynamics, disease and infection processes and phenotyping in genetic screens, and all struggle with similar technical issues in image acquisition and processing.

The significant challenges across the domain are:

Cost – almost all image analysis currently requires propietary hardware and software pipelines from commercial providers at prohibitive capital and maintenance cost.
Self Shading – Controlled growth environments generally have limited space and fixed lighting points, these cause problems with subjects self shading when camera equipment is used within the environment.
Multi-Spectral image capture – different applications benefit from light capture in different parts of the electromagnetic spectrum, e.g luciferase reporter systems, infrared from photochemical quenching.
Image Processing – linear processing with single controller machines (a design often imposed by commercial constraint) limits throughput for large image sets.

Our long term objective is to produce a low capital cost, low maintenance, open source, extensible hardware and software component system that has simple interoperability between components allowing their re-use and re-integration as part of new solutions for different image acquisition and analysis problems. This will stimulate peer-to-peer development of further software and hardware components and seed a larger repository of compatible and reuseable components developed after and outside of our project and laboratories. Our project aim is to develop simple automation solutions for moving cameras _in situ_ to prevent shading of subject plants during image acquisition, to develop automated lighting rigs for high quality image capture and produce software libraries that allow simple and quick setup and control .
The rationale behind this proposal is that low power, cheap computing platforms such as the Raspberry Pi, low cost electonic components and successful open source scientific software, like NumPy and _sci-kit image_ for Python make it possible to develop cheap, functionable and standardised elements that can be combined into image acquisition and analysis rigs and pipelines.

This project will result in concrete outputs and stimulate a great deal of future development in software and hardware for customised, yet interoperable image acquisition and analysis pipelines.

Who We Are

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Plant Cell Signalling, Circdian rhythms, System Biology

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Bioinformatics, statistics, image analysis, open source development, software engineering

Implementation

Aims
The aim of this project
1. To develop an open source image capture pipeline for multispectral image analyses of plant morphodynamics using Raspberry Pi.
2. To develop fast and lightweight parallelisable image analysis pipelines that can be run on low power computing platforms
3. To create a resource base to allow a typical enthusiastic but novice scientist to re-implement our solutions.

Methods
Aim 1.
We will develop an in growth chamber lighting and camera rig and test light filter gel and collection spectra combinations to produce evenly lit, unshaded, high contrast images. Team Webb will design and test the structures and mechanics of these rigs, optimising light levels, spectra collection filter type, camera positions and movement geometry specifications. These will be tested using brightfield and infrared illumination for continuous day and night image capture. In-development prototypes will be built with Lego construction kits and eventually production designs made for e.g 3D printed versions or bespoke components. Team MacLean will develop and create motor and actuator controller circuitry, implement controller code for automation and deployment on the Raspberry Pi platforms, create a new Python language middleware library of this code implementing an API for reuse, write documentation for specialists and non-specialists, release code under CC licence to GitHub and assist in design and production of 3D printing files.

Aim 2.
We will develop pipelines that can segment plant features from the images captured by equipment created in Aim 1 and produce software implementing the pipelines. We will ensure as that the software can be used at a high-level by typical scientists with novice level experience to reimplement and modify the pipeline elsewhere. Team MacLean will devise a small Python language library that encapsulates pipelines composed of the many algorithms in the large Python sci-kit image and NumPy suites. We will also write a companion library that can produce summary measurements and statistics of the features defined by Team Webb. To reduce computer hardware requirements we will ensure that our analysis pipelines can be parallelised, especially over a number of low cost Raspberry Pis, thereby building in a level of low cost linear scalability, we will define the minimum useable image colour channel information from the data accrued in Aim 1 to maximise the amount of information that can be processed and stored on the low-power hardware. Team MacLean will define the software such that it will enable distributed processing and can be dispatched from a remote point, e.g an end-users laptop and automatically divide labour between independent and non-interlinked Raspberry Pi worker clients, removing the need for anything but minimal network connections. All code libraries will be released as source to GitHub under CC licence and as easily installed packages through the Python Package Index.

Aim 3.
We will create a resource base to communicate our work and enable workers outside our group to reproduce, improve, modify and return their modifications back to the project. Code and digital files will be shared through GitHub under CC licences. We will produce a white paper on the apparatus, experimental setup and software and submit to bioRxiv as a preprint. The most significant part of this resource will be a blog-style series of walkthrough and build instructions in the manner of [AdaFruit](https://www.adafruit.com/) tutorials. These can be hosted on the GitHub pages system at no charge. Data from control and proof of principle experiments will be released and hosted on FigShare.

Outcomes
We will deliver the following physical, digital and publication based outcomes

Physical – blueprints – lighting rigs, illumination, camera and filter combinations and specifications
Digital – analysis code, hardware driver code, SOP software and templates, SDL component files, open source code repos under CC licences, analysed data from experiments,

Publications – bioRxiv white paper, Web tutorials – project blog.

Benefits and outcomes

The core of this project is to produce re-implementable and re-usable image analysis hardware and software in an open source manner such that it can be easily reused by groups external to our own at low cost with low experience and expertise overheads. This will be implemented on low cost apparatus permitting scalability and wide user base implementation. This main deliverable is itself a significant and useful advance to plant labs. Our project provides for impact beyond that: the modular nature of the components we intend to produce and our experience with open source software development mean that our project will facilitate the return of improvements to our project from external workers. Our project design will set the ground for a growing future community of peers collectively developing and improving the hardware and codebase in an open and easily accessible way.

Budget

Total requested: £2350

5 X Raspberry Pi 2 Model B and ancillary items, e,g wifi, cases, power supply, micro SD cards – £370
5 X 10000 mAh External Li-Ion USB Batteries – £130
1 X Lego Technics Kit – £350
Miscellaneous Components (Ethernet cables, USB cables, HDMI etc) £600
Miscellaneous Electronics, eg lighting, stepper motors, servos, wiring, prototyping boards, camera boards. £500
Travel between Norwich – Cambridge, multiple trips, £400

Post project funding for site maintenance and rolling bug-fixes and improvements will be covered by Team MacLean as part of TSL core activity.