Amplifications and wireless transmission of electrical signals from sensitive plants

OpenPlant Fund Project Title: Wireless, portable, low cost, open source hardware for monitoring plant electrophysiology

Summary
Plant electrical signalling regulates a wide range of physiological functions including stress responses to drought and wounding. Existing tools for monitoring such signals often require the uses of cumbersome and expensive equipment in well-controlled laboratory. We aim to create a low-cost measurement tools that can function robustly in the field, collecting electrical activity profiles from multiple plants. We have prototyped a tool for measuring plant electrical signal coupled with radio modules for long-distance data collection. This prototype can sense and transmit signals from Venus flytrap responding to tactile inputs (see https://www.youtube.com/watch?v=CZRlhZVgpfw for demonstration). The estimated cost of the prototype is approximately £40.

Report and Outcomes
We have prototyped a plant electrical signal amplifier coupled with a radio module. We demonstrated that this prototype can sense and transmit signals from Venus flytrap action potential (pulse width ~ 1400 ms; amplitude ~ 5 mV) responding to tactile inputs. We showed that it is possible to distinguish action potential from other disturbance using post-transmission signals. The estimated cost of each of our current amplifier - radio module is approximately £40. The amplifier, based on Backyard Brain Plant Spiker Shield, consists of a high impedance instrumental amplifier AD623 and two Operational amplifiers TLC2272. All amplifiers are powered by 5V sources from an Arduino board. Signal voltage range is set between 0V and 5V with a reference voltage at 2.5V (see the diagram). We found that this reference voltage value is necessary for achieving amplification folds close to that of ideal operations. We also decided to add another instrumental amplifier AD623 to bring voltage range down to 0-2.5V in order to match the analog input range of the wireless transmitter modules (see further discussion below). We have tried adding 50 Hz second order notch filter to eliminate DC noise but the filter attenuates too much of plant signals. We found that a plain copper wire coated with electrogel is sufficient as an electrode for plant-circuit interface. However, we noticed that electrogel seemed to be toxic to plant soft tissue (e.g. traps of venus flytrap) which turned yellowish/brownish a few days after we applied the gel. Therefore, for long term monitoring of electrical signal, we should look for less toxic alternatives.

While amplitudes and durations of action potential appeared to be consistent across different experiment repeats on the same trap, there is a small difference across different traps from the same plant. More importantly, we found that any trap whose sensory hairs remain green is insensitive to touch, neither generating action potential nor closing. Such variability of sensitivity and response across different plants (or different parts of the same plant) are likely to complicate future attempts to apply plants as environmental sensors. In order to transmit the amplified signal wirelessly over a long distance, we have utilised ZigBee communication protocol using 2 programmable XBee PRO ZigBee S2 modules, with one of the modules being configured as a transmitter and the others as a receiver unit using XCTU software. The transmitter has a built-in Analog-to-Digital Converter (ADC) function, which allows the amplified plant analog signal to be converted to digital signal accordingly. The ADC function allows a rather narrow voltage input range, thus limits the range in which the amplifier can operate as previously mentioned. We have configured the transmitter to capture the signal with the highest possible sampling rate (20Hz) to minimise signal loss. This resulted in a very high power consumption of the transmitter, which is a major drawback of this setting. The receiver was connected to an Arduino board, which was pre-programmed to convert the transmitted signal into a graphical representation as well as display numerical readings on the processing software. We were able to compare the signal readings prior to transmission with that from the receiver unit. We found that there was no detectable signal loss within 5-metre communicating range. Nevertheless, the maximal communicating distance of the prototype has yet to be determined. TEPARACreportApril2016

Expenditure

We have spent only about half of the budget (~ £2000) so far mostly on electronic equipment such as an oscilloscope, multimeter, solder kits, Backyard Brain Plant Spiker shield, etc. Other expenditure includes electronic parts and plants used in our experiment. So far, time is a more limiting constraint for us as we have been on a steep learning curve trying to familiarise ourselves with electronics lab. We might not need additional £1000 as long as we still have access to the rest of our original £4000 budget.

Are you claiming the additional £1000 follow-on funding?: Yes

Follow-On Plans

Possible sensor/controller improvement. A Programmable System on a Chip (PSoC) from Cypress Semiconductor will be used for analog-digital conversion. We plan to use the CY8KIT-059 PSoC® 5LP Prototyping Kit by Cypress semiconductor. The use of such prototyping kits manufactured in large batches would allow us to lower the cost (~ £7.5 total cost per kit as oppose to £20 for Arduino) and better analog to digital conversion (20 bit as oppose to 10 bit for Arduino). The PSoC is a novel programmable electrical chip that has both programmable analog and digital components. This will allow the use of just one integrated circuit to make the device. We will also expand our current wireless network work by developing an internet data logging system which will allow us to deposit processed data directly onto an online interface. To achieve this, we will incorporate an XBee wifi module into our current receiver unit design. The wifi module will enable the Internet access and allow data transmission from the microcontroller onto the online interface. We will also look for an alternative of XBee module in order to further reducing the cost of the prototype such as XRF module by Ciseco.