Ubiquitous Computing Coursework

Petru-Marian Burlacu
Edinburgh Napier University
40285539@live.napier.ac.uk

Peter Philips
Edinburgh Napier University
40290201@live.napier.ac.uk

ABSTRACT
This document provides an overview of the proposed experimental system that has been developed over the duration of the Ubiquitous Computing module. The tool gathers electrical activity from the surface of higher plants and measures the impact of external stimuli such as human interaction. The frequency based gathered data is used to produce a meaningful output that illustrates the behavioral changes in a plant.

Author Keywords
Ubiquitous, computing; coursework; plant, electrical, activity; electrical, potential; produces, sound, greenhouse, atmosphere; plant, personality.

ACM Classification Keywords
HCC. Human-Centered Computing: Ubiquitous and mobile computing

INTRODUCTION
The purpose of this project is to determine if it is possible to measure electrical potential in higher plants and if the gathered data can be used to create synthesized sound. Higher plants can be defined as plants with advanced functionalities or relative complexity, such as vascular plants. The system is to be used as a potential addition to Lion’s Gate Garden Greenhouse initiative, contributing to the overall atmosphere by showcasing the behavior of plants.

The measurement of electrical potential is used broadly in neurobiology and it can be substantiated by previous academic research [1]. The action potential (AP) can be found in most of the living things and researchers use extracellular and intracellular methods of data gathering to identify variations in activity. Most of its use cases are in animal electrophysiology [2]. This document, describes how extracellular recordings were used on a higher plant to produce sound. Additionally, we used environmental factors to investigate potential behavior variations.

DEVELOPMENT
For the development process, the team started with research on electrocardiograms (ECG) functionality and if it would be possible to pick up the low electric activity in higher plants [3]. It was learned that plants produce a noticeable amount of activity to be picked up and processed to produce measurable data. There are precedents available to document upon and order our components based on the findings, as this was the main concern before moving forward.

The initial approach for the first prototype had minimal functionalities in comparison to the final result, expanding on it based on the available time and compatibility between the components. A schematic with Fritzing [4] with all of our components was developed.

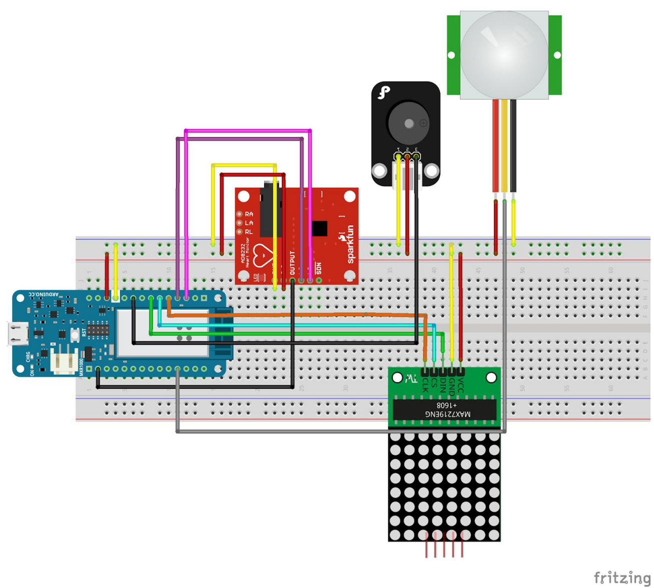

Figure 1. Schematic with all of the modules.

Each module has a VCC (3.3 volts) connection and a Ground (Earth) connection represented by the red and yellow wires respectively. The Electrocardiograms (ECG) module’s LO- pin is connected to port 8 and the LO+ pin is connected to port 9 of the Arduino. The analog output is connected to the A0 port of the Arduino which is where the frequency is read in the code. The speaker is connected to port 14 and the PIR sensor, 2. The LED matrix is connected to ports 10, 11, 12 by respective pins CLK, CS, and Din.

The schematic was used as a point of reference during the development process as iterations of the prototype were completed. The core feature of the plan was to gather the electrical activity in plants and transform it into sound. In order to accomplish the goal, a module that would be used for input to gather data and a speaker module for the output were required.

The electrical potential in theory should be related to the electrical activity in plants. In this case, it is measured using extracellular method, by making use of additional Arduino modules. Electrocardiograms are commonly encountered in medical fields were used to gather data.

Three electrodes (PADS) were placed on the surface of the plant, in most cases leaves, and it is required to have a complete circuit.

Figure 2. Electrocardiogram module on the plant

One pad is being used as the reference and placed between the other two elements. This approach is used to correlate electrical activity to a plant's behavior and physical influences in its environment. The module was connected to an Analog (A0) and the produced data was represented in hertz. The code used is an alteration of a heartbeat sensor project [7].

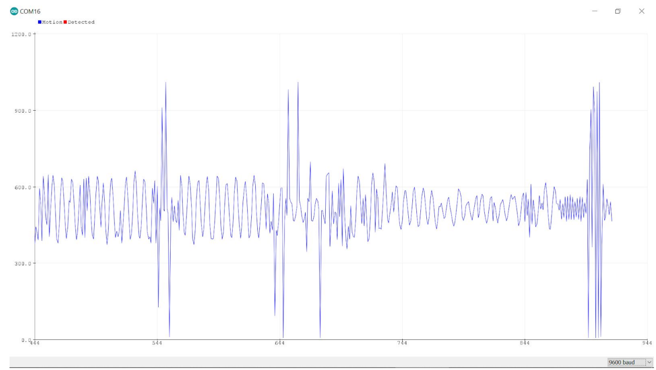

Figure 3. ECG data, represented in Hertz

Figure 3 from above represents the electrical activity of a subject plant for a set period of time. It was difficult to establish a constant behavior of the plant, due to inconsistency in the environment such as temperature, system placement and even humidity. After performing multiple tests in a constant environment a pattern was determined for the potential activity. The normal activity is represented in Hertz between ranges of 300Hz to 700Hz.

The data investigation provides meaningful clues to how environmental factors on higher plants can influence their electrical activity. In the provided illustration (Figure 3), it can be observed the drastic variation in activity when a plant is in contact with external objects, the highest variations present in human contact. The plant reacts to human touch and the receptors send signals charged with our electric activity throughout its body.

Optimal environment conditions are important to produce accurate representation of electric activity in plants. The consistency in data, in this case, is relevant for data analysis but can be neglected for sound generations. The important factor for producing tones is having a noticeable difference in detected frequency, especially when introducing external environmental changes such as human contact with the plant. As previously stated, the variations can be identified in the data. The default Arduino tone method was implemented to produce tones representing frequency variations. The method takes a duration variable, frequency and an output pin for parameters [5]. The output pin connects the produced sounds to the audio module. The two functionalities described above represent the core of our project and address the initial questions. (Appendix 1 – Initial proposal)

From the gathered data it can be determined that higher plants produce distinct electrical activity and that it is possible to collect the signals with an ECG module. If the timescale of the project allowed, specific sound libraries that are available on the internet could be used to transform the default Arduino tone method output into more pleasant and meaningful music. But the working system proves that it is possible to create synthesized sound to represent a plant's electrical behavior.

The next step was to connect a passive infrared sensor (PIR) to act as a trigger for the system. This could potentially limit the output capabilities and can address the power consumption concerns. The PIR sensor detects when someone passes by, with a restriction on the detection time that is directly related to the audio output time, making sure that the trigger is not activated during the demo to start a new cycle. Based on power consumption it is possible to adjust the intervals for output and PIR sensor trigger.

The project followed the predicted time frame. It allowed for a third layer of functionality to be included in the system. We connected an LED module that displays a meaningful output based on the gathered frequencies. It was configured to display a pulse with each frame representing a new variation in electrical activity of the higher plant. A third party application was utilized to easily convert our frames into bits that would later be used in our code for output [6].

The output data has been recorded on ThingSpeak.com which is a cloud data collection web app. When connected to a Wi-Fi source, the device will upload data to this channel:
https://thingspeak.com/channels/928770/private_show. The device will upload data when the PIR sensor is activated and will show the time of detection on Thing-Speak. The device will also upload the frequency of the plant at the time of detection.

The source code for the final iteration of the project can be found here:

https://create.arduino.cc/editor/PeterPhillips1995/dc451e46-ed08-4362-9738-e81516dc60ea/preview.

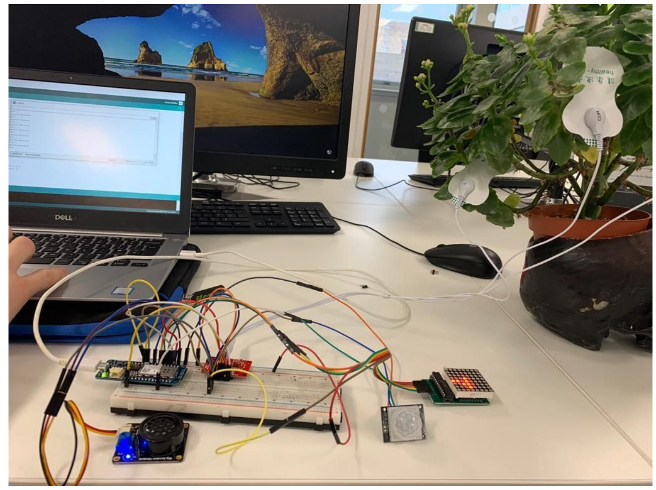

Figure 4. Final prototype version

PROTOTYPE's HOUSING

The final prototype successfully incorporated all of the planned features. Additionally, the prototype includes a designed plant pot (housing) that integrates our components efficiently.

Figure 5. Prototype's 3D Housing Model

The illustrated prototype housing comes with drainage functionality and a foundation that retains the water and can be detached to eliminate the surplus of liquids. The space for Arduino system is located between the external walls and the plant's interior holder. It has a lid to hide the Arduino modules, allowing only for the plant with the ECG module to be visible.

USER FEEDBACK

Feedback gained from the users focused on the output capabilities of the hardware. The sound of the hardware that is based on the frequency being recorded of the plant at that time, is abrupt and not particularly melodic. If implemented in the Lion's Gate Garden it could potentially be annoying and provide a negative user experience. To improve this as previously mentioned, more complex sound libraries could be implemented and higher quality speakers could be used to create a more melodic and appropriate sound to broadcast the plant's electrical identity.

PRIVACY CONCERNS

Because information being gathered is about the environment the subject plant is placed in, such as temperature, location or any other specific features, there is no risk of intrusion. The proposed system collects electrical activity of the subject plant, interpreting the information in Hertz, processing it to produce tones. Depending on the system placement, intrusion produced by the audio output might be of concern. But our system is designed to be placed in the Lion's Garden public area and it would have the necessary permissions in case of implementation.

For future use, in case of commercial implementations, the Arduino's commercial usage policy permits the utilization of their components.

CONCLUSION

In conclusion from the experiments and the team's research it can be determined that physiological behavior in higher plants can be affected by electrical currents. Allocation of the necessary nutrients, light detection and reaction, adaptation to different environments and meteorological volatility such as temperature, humidity, water, light and transmit the information throughout the cellular complex in a plant. Plant neurobiology refers to this process as cell-to-cell signaling.

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Appendices

Appendix A - LED Matrix frames