Biological Internet of Things

A review and study of hybrid biological IoT systems

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***Abstract*—Plant cells have intrinsic bioelectric signals to communicate with themselves regarding external stimuli, these signals can be harnessed and connected with digital devices for use in novel applications. Since plants are commonplace beings that are usually overlooked, especially by intruders, plants that have been connected to digital devices can act as covert sensors within an IoT system surveilling important places such as warehouses for theft and taking necessary actions using other devices connected in the same system. The plants are capable of sensing movement, touch , and light. Tactically placed plant sensors are indispensable to security as well as an sustainale aspect to the environment. This paper explores the applications a digital-biological hybrid plant based IoT system can be used in.**

***Index Terms*—Keywords: Internet of things, biohybrid systems, cyborg botany, plant spikerbox, plant sensing.**

I. Introduction

Over the past century human/mammal-computer interaction has seen leaps and bounds to the extent that thought based control of prosthetics and even extraction of music from scanning brain signals is possible [1] . However a different kingdom of living beings can also be integrated with modern computer systems - plants. Plants switch their ubiquity and simplicity can act as crucial living sensors and actuators, aiding in various new activities. In this paper, the commonplace aspect of plants is exploited to architect a surveillance system.

In many surveillance cases, the existence of sensors lead to perpetrators directly targeting and compromising the sensor or camera. A more covert, and environmentally integrable system will be of extreme value. For this reason, we propose converting plants into covert sensors for use in surveillance. Plant cells have intrinsic bioelectric signals to communicate with themselves regarding external stimuli, These signals are harvested and connected with digital devices for use in various applications. Plants that have been connected to digital devices can act as covert sensors within an IoT system, surveilling important places such as warehouses for theft and taking necessary actions using other devices connected in the same system. The plants are capable of sensing movement, touch, and light. The plant signals are harvested using specialized signal processing units, which is then passed on to conventional electronic apparatus for making decisions within the IoT system. Tactically placed plant sensors can be indispensable to security as well as an aesthetic aspect to the environment. Apart from security aspects, certain gestures on the plants can be used for interaction with the daily environment as well, and in the future integrate organic as well as digital entities for a truly inclusive and sophisticated internet of things, which will open new realms of data and interaction to explore.

A. Concept of operation

Intruders often target surveillance systems by detecting them using their EM signature or if they are an activated sensor through specialized devices. Plant based IoT systems combine the functionalit y of multiple devices without having to source expensive, intricate and breakable sensors.

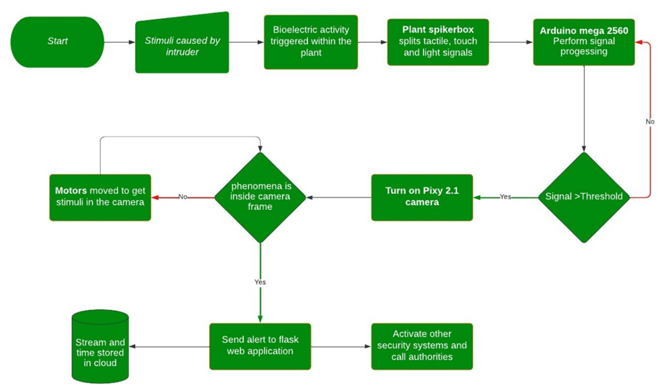

Fig. 1. Concept of system operation

B. Motivation

While this paper focuses on surveillance and detection of external stimuli through plant signals, the project has scope in the future to permeate more advanced applications. Given that vertical gardens, smart farms and green city initiatives are seeing a boom, having precise measurement and interconnection will allow for a more connected and sophisticated world that better incorporates plant as well as animal life towards a more sustainable world. This is a pilot project to understand plant signals and measure them in accordance with existing literature.

In a sample operational situation, the plant detection system is placed near a pathway an intruder must use to gain access to different parts of their target. If an intruder passes by the plant's detection system, the plants will produce some electrical signals which will be analyzed and processed. The plant has to be capable of exhibiting a thigmonastic response, meaning it should have a quick and active reaction to touch, sound or light and physically respond/move must move to the same. This is important because the movement of the plant is caused by a potential difference and a corresponding spike, which is what is measured as a trigger signal. Upon detection of the trigger signal, a hidden camera will be turned on and will track the anomaly/intrusion.

This specific system will ensure that the intruder will not be aware that they are being tracked. Since the plants act as covert sensors the factory officials will be alerted in no time. Furthermore, usage of plants is a sustainable and more supply chain friendly alternative as it is readily available and need not be imported in most countries.

C. Challenges

Some of the major challenges are that plant signals are very weak since they are non-motorized, passive beings that do not generate large electric or ionic potential differences. For this reason, even with sensitive electrodes, identifying and differentiating different signals is challenging. There are two major options to carry out data acquisition, invasive and non-invasive. Invasive method of signal acquisition involves penetrating the epidermis of the plant using an electrode and reaching the core, while this promises high resolution , high amplitude signals, it might adversely affect the plant as more signals are taken throughout the plant body over time. On the other hand, a non-invasive method, while not promising in terms of acquiring signals, will be safer for the plant and more convenient for experimentation.

II. Literature Review

In the present, with existing issues such as global warming, it is clear that a eco-conscious approach has to be taken to increasing interconnectivity and interoperability in the advancement of IoT technology. On top of sustainability it is important to understand the underlying biology and better integrate artificial systems into existing biological systems for a more holistic ecosystem. Plants have been known to have more than 15 senses, they are stationary and have healing properties [2]. These properties make them ideal candidates to study the usage of a biohybrid IoT system.

Furthermore, movements such as industry 4.0 push for a varied and decentralized set of sensors and actuators connected through the cloud, however raw material restrictions and supply chain shortages make this a cumbersome and painstaking process [3]. The ubiquity of plants and their various capabilities will counteract the problem with traditional sensors.

Integration of hybrid sensor based plants into the human environment encourage better human-environment interaction [4]. This study made a living and robotic plants as markers in the environment to encourage recycling and better the aesthetic of the location. This study involved two discrete open loop systems sparsely interacting with each other. The plant was not completely connected with the robotics sensors, but the plant acted as the actuator, moving towards the recyclables. In our study we would like to utilize plants' sensing capabilites, hence further literature was expored.

Existing plant-electronics hybrid sensing projects involve injecting the plants with highly conductive electrodes, then sensing them using another set of extrinsic electrodes Plant signals in this case are very clear and can be processed without sophisticated signal processing tools. It can be used as an interface for interaction with digital devices. The intrinsic conduction fluidic polymer electrodes used were PEDOT - poly(3,4-ethylenedioxythiophene). The plant is placed in a PEDOT solution, and the solution is allowed to penetrate the plant xylem, which now conducts all of the intrinsic plant biosignals. The extrinsic electrode must be placed such that it is in contact with the intrinsic conductive polymer. The problem with this approach is that the polymer might interfere with the plant's intrinsic functions and furthermore, it is not a permanent solution. The polymer electrode eventually gets broken up, hence an open circuit is made inside the plant, making any reading unreliable [5].

One alternative to the chemical embedding approach is using optical nanosensors and having the plant absorb them [6]. This approach makes the system completely self powered and does not involve any external power source. FUrthermore there are no problems with continuity or circuit breakage causing obscelesence in the future. This approach involved allowing plants to absorb nanosensors, then using a laser analyzer and observing the emission spectrum from plants. This specific study designed and utilized nanosensors that detected arsenic in the soil. This approach, however, is more expensive and too specialized, each type of data to be collected involves a different nanosensor to be designed.

Easterly, D. Bio-Fi: Inverse Biotelemetry Projects. In the Proc of the 12th annual ACM international conference on Multimedia. Spore is a self-sustaining ecosystem to visualize flow of stock prices. These works utilize only the function that converts environmental energies into plants' behavior. This paper involves use of electrodes as well as actuators to influence the ecosystem.

The most appropriate approaches found for our study were by [7], [8] and [9]. Each of these approaches used a combination of non invasive external electrodes and cheap, widely available sensors that rather then detecting the environment, detected the plants' biosignals either using their own sensing rig or a commercially available system such as the plant spikerbox [10]. Each allowed the plant to sense and relay external information such as stock pricing, light or movement. Studies also used plants that exhibited rapid movement such as the Mimosa Pudica or the venus flytrap, which have the highest biopotential difference from baseline. This careful selection of plants and external sensors allow the avoidance of invasive chemicals, or unideal sensors. Hence, a similar approach was adopted by ourselves. The plant spikerbox and Mimosa Pudica along with a portable computer such as raspberry pi is ideal to the current paper.

III. Requirements

A. Hardware Requirements

- Plant spikerbox: Spikerbox is used to separate, sense and preprocess the various signals from the plant by classifying each signal like proximity signal, touch signal etc.
- A laptop: To connect with the plant spikerbox for experimentation
- Raspberry pi: To portably analyze the plant signals acquired from the spikerbox
- Pixy 2.1 camera: Performing cv operations and is used for tracking the people.

B. Software Requirements

- Arduino software: This is the software used for Arduino programming
- Plant Spikerbox software: This is the software made by the spikerbox association to visualize and filter out the unnecessary signals from the plants.
- Pixymon: This is a software used to get the visual feedback from the pixycam and perform OpenCV operations on it.

IV. Implementation and methodology

The primary aspect of the implementation involves collecting plant biopotential signals through experimentation. The procedure for the same is outlined below.

A. Plant data collection

For training the system and setting threshold a set of controlled experiments were conducted. The plant was placed in a dark room approximately half hour after watering it. The following independent variables were used:

- Light stimulus
- Wind stimulus
- touch stimulus

Light stimulus involves flashing a 50 lumen torch at the plant leaves. Wind stimulus involves using a hand fan to do 5 oscillations in the direction of the plant. Touch stimulus involves using a plastic stick to displace the respective plant stem by 1 cm.

The above stimuli were carried out for 2 seconds continuously for a set of 10 repetitions. Between each repetition, a 5 second gap is kept for differentiating between the signals.

Fig. 2. Setup of mimosa plant with spikerbox

In order to carry out the above actions, each component of the plant spikerbox had to be effectively utilized.

- The spikerbox has several components, the main parts include:
- Electrodes - interfaces with the plant and collects signal
- Electrode connector clips - Conencts wires to PCB
- Signal jack - connect PCB to laptop for live viewing
- Battery - allows portability and powers system
- spikerbox PCB - the actual amplifier and DAQ system
- conductive gel - improves signal collection

Fig. 3. All listed components of spikerbox

Procedure to conduct experiment:

1) Connect red electrode to the plant by wrapping it around a joint on the plant
2) Place 1 drop of conductive gel on the point where the electrode makes contact with the plant
3) Place the ground electrode pin on the soil next to the plant
4) Clip the red and black electrode wires to the electrode connectors
5) Plug in the electrode connector on the jack provided in the spikerbox
6) Connect the green signal jack to the spikerbox and another device of choice(in this case a mobile phone was used)
7) Place 9V battery in the box's power port and connect it
8) Flip the power switch to turn the spikerbox on
9) In the spike recorder application on the companion device, add the plant filter to only see the plant signals

V. Results and Discussion

Spikes detected from spikerbox:

As previously mentioned, three sets of experiments with three stimuli were carried out. The figures 4, 5, 6 below illustrate the data collected with the 3 stimuli.

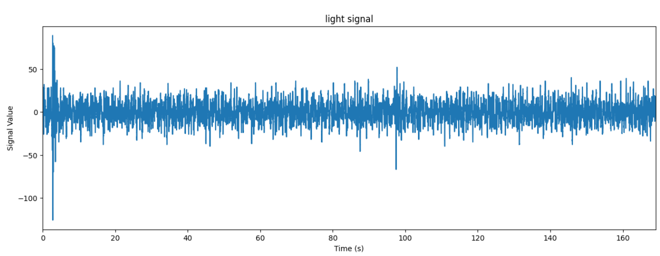

Fig. 4. Spikerbox data of Mimosa reaction to light stimuli

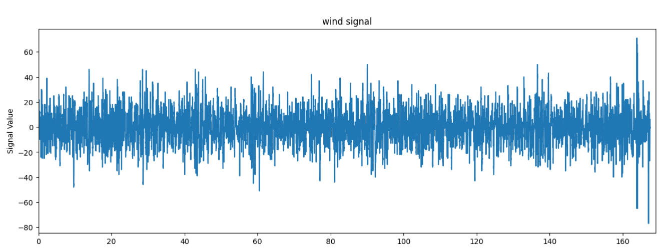

Fig. 5. Spikerbox data of Mimosa reaction to wind stimuli

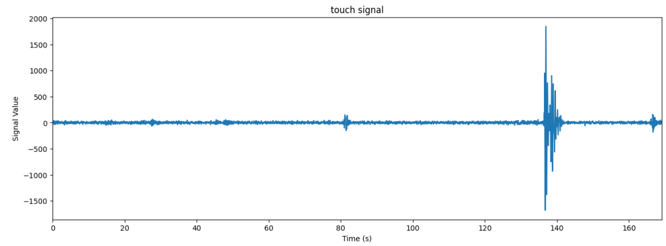

Fig. 6. Spikerbox data of Mimosa reaction to touch stimuli

In the generated graphs, there is no discernible difference between ambient noise, burst noises and signals that were supposed to have been generated. In order to find this a low pass filter with the threshold as 15 hertz was used, since the backyard brains website suggested that plant signals are in the lowest 1-10 range.

This approach, however, led to the graph completely flat-lining. Therefore ,an alternative method was tried. MFCC conversion was a method utilized for plant hybrid signal filtering and processing [11]. MFCC is a feature extraction method where sinusoidal components of waves are represented as coefficients.

This signal and noise can be discrete. It involves selecting a window size, setting a frame length and then finding the discrete fourier transform of the signal and finally triangular filter banks are applied, upon which the final heatmap of the signals can be retrieved. Generally, at the end just the signals must be noticeable in the heatmap, however when applied for the data acquired through the spikerbox, the entire length of recording was marked high in the final MFCC heatmap

The electronics aspects of the BIoT system worked as shown in Fig. 7 and Fig. 8.

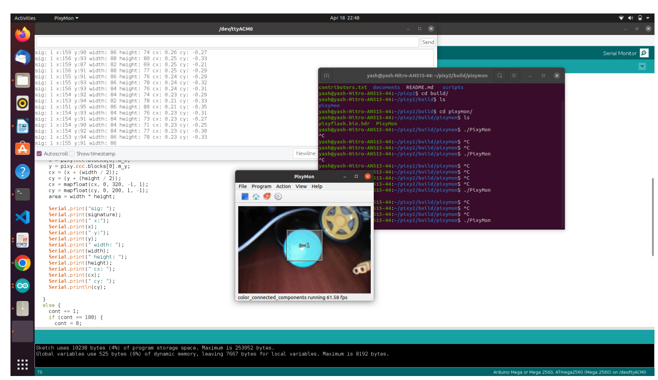

Fig. 7. Screenshot of Object detection from camera

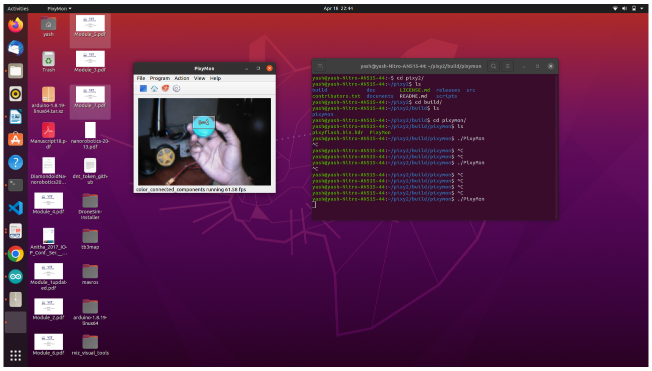

Fig. 8. Screenshot of algorithm adding bounding box to detected object

VI. Conclusion

In conclusion, a thigmonastic plant such as Mimosa Pudica along with special amplifiers can act as multiple sensors and covert sensors in unique situations, hence acting as a low power sustainable IoT system. The plant signals, however, for various types of signals are indistinguishable, a method to find and differentiate these signals will truly unlock the potential of this specific device.

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