DRPD-ROF2017-XXXXXXXXX

Wireless Sensor System for Beehive Health Monitoring

- Co-PIs:

Joaquin Casanova Electrical Computer Engineering, jcasa@ufl.edu, 352-294-2024
James Ellis Entomology and Nematology, jdellis@ufl.edu, 352-273-3924

- Start Date: May 1, 2017
- Budget request: $80000

Abstract

Pollinators, such as honeybees (*Apis mellifera*) and bumblebees, hummingbirds, wasps, and butterflies, serve an important ecological function: allowing plants to reproduce, and in so doing, producing the majority of food crops relied on by humans. Honeybees themselves are responsible for billions of dollars in crop value. The past decade has seen a sudden increase in honeybee winter losses, which has come to be known as Colony Collapse Disorder (CCD). The causes and solutions of this phenomenon are still an active area of research. It's a multifactorial problem, with several potential causes working in concert, among which are disease (Deformed Wing Virus), pests (*Varroa destructor*), immunodepression by pesticides, and loss of honeybee habitat.

To address this concern, the US government established a set of research goals and recovery actions in the Polinator Research Action Plan. Research goals include establishing pollinator health baselines, assessing environmental stressors, restoring habitat, supporting land managers and beekeepers (including best manangement practices), and pollinator monitoring and study. The aim of this project is do develop an inexpensive sensor system for monitoring hive health. Such a system, if widely adopted, would allow stakeholders to monitoring their own hives, and allow researchers to collect data nationwide easily. Combined with additional geographical, and land management data (ie, pesticides, herbicides, nearby crops), this data network would aid in highlighting causes of, and developing BMPs to mitigate, CCD.

An inexpensive, wirelessly connected beehive monitor could achieve widespread acceptance. Several easily measured variables include: bee traffic and shape (measured through a camera at the high entrance; presence of a queen and hive activity (measured through the audio frequencies produced by the hive); and honey content (measured through the electromagnetic characteristics of the hive body). These metrics address disease, as worker bee shape changes under certain disease stresses; potential for swarming; and availability of food, and indirectly habitat, through honey content. All three of these sensors may be devised by repurposing off-the-shelf sensors, and integrated into a single system with transmits it's data to a server wirelessly. This research aims to develop and test such a system, with hope of commercialization and widespread acceptance.

Project Description

1 Introduction

The goal of this project is to develop and test a multimodal, noninvasive, networked beehive health monitor, that would be distributed among apiculturists to aggregate data on beehive health in real-time.

Pollinators perform an important ecological service in the reproduction of 70% of plant species. Of pollinators, honeybees (*Apis mellifera*) are special in their gathering of large amounts of pollen for food, in the process transferring pollen between flowers. Colony Collapse Disorder (CCD), named in 2007, reflects part of a decades long decline in the population of managed honeybees [21]. CCD is characterized by a sudden colony die-off where worker bees fly off and abandon the hive. This is of particular concern, as agricultural production of pollinator dependent crops is increasing to meet the food needs of a growing human population.The USDAs Report on the National Stakeholders Conference on Honeybee Health provides a basis for understanding the root causes of these population declines [6]. Several causes have worked in concert. Invasive *Varroa destructor* mites are the primary concern, detrimental on its own and known to amplify viruses' effect, including Deformed Wing Virus. Lack of forage leads to decreased food stores, and suppression of bee gut microbiota. Depressed immunity also results from chronic sublethal pesticide exposure. The changes result in physically detectable changes to the bees appearance and foraging behavior, as well as the hive as a whole, in terms of swarming, food stores and population.

According to the Pollinator Research Action Plan goals [11], the aim of US government-sponsored research is to reduce honeybee overwintering losses to no more than 15%. Part of this overall goal is to establish a baseline for the current state of honeybee health. While there are honeybee censuses [24], there exists no monitoring system for the health status of managed hives in the US. Such a network of standardized beehive monitors would enable researchers to mine data associated with crop and apiary management practices with measures of colony fitness. murphy2015big Our projects aim is to design, build, and test a noninvasive, wireless, multimodal beehive monitor that could be used nationwide. In particular, our system would implement visual, audio, and weight sensors to monitor bee health and behavior, as well as hive food content, without having to disturb the hive. As such, apiculturists could install the station easily. With 3G connection, these stations could upload data to a centralized database, enabling real-time monitoring of trends in beehive health. This could form the basis for a network similar to the weather station network of WeatherUnderground. In this way researchers could understand variation of colony losses over space, time, weather, and management practices. Sensors have been used to monitor beehives in previous works. In a similar vein, researchers in Ireland have combined visual, infrared, load cells, particulate monitors, and gas analyzers in the b+WSN and 3b projects [15,16]. Beelab is an open source Canadian project, providing apiculturists with a highly simplified kit for hive data collection [17]. So far, there is no US based project with these goals. Furthermore, previous works are invasive to the hive to collect meaningful data placing a night-vision camera inside the hive may produce useful information, but would disturb the hive and would have reduced acceptance among stakeholders.

It's clear that several sensing modalities can be useful for monitoring hive health, and be non invasive. Researchers have implemented video and computer vision systems to monitor bees outside of the hive with success [1, 22]. And while the presence or lack of certain miticides might be most indicative of CCD, increased bee head size and asymmetry are also indicators [20] that can be detected with computer vision. DWV can be detected visually as well [8]. Sound is an indicator of hive status as well. The queen emits a particular sound prior to a swarm (piping), and this has been detected in previous works using microphones [9, 10]. Hive weight can indicate activity and food stores, and monitoring efforts have been made in the past [14], requiring load cells. Such a measurement system would allow noninvasive monitoring of the colony's food. However , load cells are cumbersome to install, so an alternative will be devloped, expecting a technique known as time-domain reflectometry, in which a pair of electrodes on the surface of the hive propagate a pulse, whose travel time serves as an indication of the hive's dielectric constant [7]. The higher the dielectric constant, the longer the travel time. The dielectric constant of honey is significantly different than that of air or wood [12], so hive honey content can be monitored in this way.

By combining computer vision, audio monitoring, and weight/honey measurement, a hive's health status can be well described. Further, with access to wireless networks and solar power, and meta-data regarding management practices, this information can be monitored remotely and aggregated for analysis and prediction. Keeping the system simple, inexpensive, and noninvasive will increase acceptance among stakeholders.

The specific objectives of the proposed research are to develop a system are to alert farmers to health problems with their hive, through visual, audio, and electromagnetic sensors, and to network the sensors to permit aggregation of data on hive health for future analysis. These objectives meet the USDA's priority of elucidation of individual or interacting factors that affect pollinator populations that will lead to the development of novel tools and technologies to mitigate their losses. The proposal largely depends on established techniques, but this seed grant will allow us to establish a program of beehive sensor research. Potential future outcomes include novel sensing modalities, such as electromagnetic honey content and pesticide concentration monitoring.

2 Approach

The planned research is comprised of five main tasks: computer vision algorithm development, audio sensor design, electromagnetic sensor design, sensor integration and programming, and field implementation.

2.1 Computer Vision Algorithm Development

In order to provide targeted data, images of the hive entrance need to meet certain requirements. Images must only be acquired when workers are present, and workers' features need to be extracted. Thus, a program will be developed that takes a video stream and captures images when bees are present, as in [4]. The first part of the CV algorithm must simply detect the presence of bees at the hive entrance, through simple thresholding (dark bees are easily distinguished against the white paint of the hive entrance) or more advanced techniques such as Support Vector Machines trained on bee features [1]. Then the individual bees will be tracked frame-to-frame using a method such as optical flow [13] or nodal analysis as in [4]. Finally, the individual bees shapes must be determined and reduced to a set of shape parameters, as with Hough circle fitting [25], for exampl. Additional machine learning algorithms will be implemented and trained using human experts to distinguish healthy from diseased bees. The computer vision algorithm will be developed using test images and existing video on a desktop computer.

2.2 Audio Processor Design

A microphone on the side of the hive will pick up audio and amplify sounds produced by the bees, after which it will be digitized and processed. The microphone/amplifier/digitization circuit will be designed and constructed. Audio frequencies below 1 kHz are sufficient for detection of swarms. A software algorithm that analyzes the spectral content will be developed that pinpoints swarming events following the techniques described in [10]. Evidence also suggests that queens can be detected; even though their sound is siilar to workers, they generate a stronger tone between 400 and 550 Hz [9]. Potentially, there is a link between hive sounds and exposure to airborne toxins [3]

2.3 Honey Content Sensor Design

Monitoring the honey content will be done in two ways: first, through measurement of the hive weight [14], a standard technique, and second, through time domain reflectometry, a novel technique in this application. TDR has been applied extensively in measurement of soil water content, such as with the commercially available soil probes from Acclima [2, 18], due to the high dielectric of water relative to dry soil. Such a commercial sensor could be easily repurposed and attached to the exterior of the hive for purpose of hive monitoring, and calibrated against the weight of the hive. A hive weight monitor will be designed to support the high weights (¿200lb) of a full hive, and measure small changes with time. This can be done using off-the-shelf load cells and amplifiers. The signal will be digitized and logged and used as a reference against the electromagnetic sensor.

2.4 Sensor Integration

The three sensing systems will be integrated into one datalogging system using a low-power embedded computer, such as the Raspberry Pi [23], which would also implement the CV algorithm. This computer would perform the image processing and log all data. In addition, it would serve the data to a web interface and central database that will be designed and programmed for this task.

2.5 Field Implementation and Controlled Expermients

Finally, the sensors and embedded computer will be installed on a test hive. A weatherproof housing will be designed and fabricated. The system will be powered by solar cells. A 3G connection will allow wireless data upload. The system will be monitored and debugged during the following 3 months. At least 10 hives will be divided into different treatment groups. Several relevant treatment variables could be controlled artificially to evaluate the systems efficacy, including presence of a queen, and Varroa and small hive beetle infestations, etc. Sensor measurements (honey content, bee morphological measurements, audio spectra) can be tested statistically for significance with regard to these explanatory variables indicative of hive health.

3 Timeline

The project will be completed over 18 months. Tasks 1-4 will be performed during May 2017 through August 2017. Task 4 will be completed in the 3 months following 1-3. Task 5, field implementation and testing, will follow, for a duration of 3 months. Finally, the system should be ready for a field experiment in Spring of 2018, for nine months, after which data will be analyzed and papers written for 3 months.

4 Pitfalls

There are several potential difficulties with this project. First, computer vision algorithm development is challenging, and depends largely on the quality of the test dataset. Gathering enough extant test video of beehive entrances, and formulating an effective feature extraction and analysis algorithm, may prove more time-consuming than anticipated. Second, the required sensitivity of the microphone and load cells are as yet unknown, and method of dynamically adjusting both for environmental factors (ie, loud noises and hive shifts due to maintenance) will need to be developed. Third, the field implementation will need to be kept highly power efficient to support such processor-intensive activities, such as computer vision, as well as wireless networking. At worst it may require supplemental power, perhaps instead relying on power-over-ethernet. Finally, the system cost should be kept low enough that it would be readily accepted by apiculturists, so that data could be aggregated.

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Key personnel and roles

- Joaquin J. Casanova

  Expertise: Agricultural sensors, computer vision, machine learning

  Role: lead for system design and development

- James D. Ellis

  Expertise: honey bee pathology, ecology, toxicology and behavior

  Role: lead for beehive controlled experiments

Budget

Total :

1. **Salaries**

   Dr. Casanova salary and fringe at 25% (excluded from budget) – $38216

   Dr. Ellis salary and fringe at 25% (excluded from budget) – $71382

   Graduate student, salary 18 months – $37500

   Graduate student, fringe 18 months – $7650

   Graduate student, tuition 18 months – $11873

2. **Materials**

   Sensors – $500 per hive for at least 10 hives, and backup systems - $10000

   Test equipment – $5000

   Apicultural supplies – $5000

3. **Additional costs**

   Publication and travel – $6000

4. **Indirect Cost** (excluded from budget) – $37476

5. **Total: $83023**

Continued Support and Commercial Potential

This project may be viewed as a preliminary study - significant advancements could be made as we increase the scale and advance then sensors. Once apiculturists are widely using such a sensor platform, this bacomes a very useful tool. Aggregating hive data, along with weather condition, location, and nearb pesticide and herbicide usage, can elucidate unknown correlations that will highlight causes of CCD. Additionally, further advances in sensors may be developed and implemented, such as bee tracking in the field with lasers [5] or infra-red monitoring of bee population [19]. Potential future sources of funding include:

- USDA NIFA – AFRI Food Security Challenge Area
- Fresh From Florida – Specialty Crop Grant
- DOI – Competitive State Wildlife Grant Program

These types of sensor systems would become inexpensive on a large scale so it is a good candidate for commercialization, and there is certainly a market for it among apiculturists and apicultural researchers.

Biographical Sketch: Joaquin Casanova

(a) Professional Preparation

Electrical Engineering PhD, UF, Gainesville, May 2010

Agricultural and Biological Engineering ME, UF, Gainesville, December 2007

Agricultural and Biological Engineering BS, UF, Gainesville, December 2006

(b) Appointments

Research Assistant Professor, University of Florida, August 2016-present

Senior Engineer, University of Florida, November 2013-June 2016

Research Engineer, USDA, May 2010-October 2013

(c) Products

30 technical publications in peer-reviewed journals and conference proceedings. 2 patents awarded. Most closely related to the proposed project:

1. Schwartz, R. C., **Casanova, J. J.**, Bell, J. M., & Evett, S. R. (2014). A reevaluation of time domain reflectometry propagation time determination in soils. Vadose Zone Journal, 13(1).

2. **Casanova, J. J.**, Schwartz, R. C., & Evett, S. R. (2014). Design and field tests of a directly coupled waveguide-on-access-tube soil water sensor.Applied Engineering in Agriculture, 30(1), 105-112.

3. **Casanova, J. J.**, O'Shaughnessy, S. A., Evett, S. R., & Rush, C. M. (2014). Development of a wireless computer vision instrument to detect biotic stress in wheat. Sensors, 14(9), 17753-17769.

4. **Casanova, J. J.**, OShaughnessy, S., & Evett, S. (2013, November). Wireless computer vision system for crop stress detection. In ASA-CSSA-SSSA Annual Meeting Abstracts (p. 123). ASA-CSSA-SSSA Annual Meeting Abstracts. Session 196-7.

5. **Casanova, J. J.**, Evett, S. R., & Schwartz, R. C. (2012). Design and field tests of an access-tube soil water sensor. Applied Engineering in Agriculture,28(4), 603-610.

6. **Casanova, J. J.**, Evett, S. R., & Schwartz, R. C. (2012). Design of access-tube TDR sensor for soil water content: Testing. Sensors Journal, IEEE,12(6), 2064-2070.

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(d) Synergistic Activities

1. **Main Activities** Dr. Casanova is a research assistant professor in the Department of Electrical and Computer Engineering at the University of Florida. His main research activities are electromagnetic sensors, instrumentation design, and machine intelligence applications. Previously he did research with the USDA in these areas and developed chemistry instrumentation for UFs Chemistry Department.

2. **Professional Membership**

   - 2004-present Member American Society of Agricultural and Biological Engineers (ASABE)
   - 2006-present Member Institute of Electrical and Electronics Engineers (IEEE)