A Scalable Early Warning System: Electronic Detection of Corn Rootworm Beetles With a Microcontroller-based Sensor Network

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January 17, 2020

Abstract

The loss in farm revenue associated with corn rootworm infestations in the United States is greater than a billion dollars per year.[3] Adult females begin producing eggs a few weeks after emergence, typically in mid July. The adult beetles can be monitored using an adhesive trap strapped to a corn stalk. However, it is burdensome to inspect the dozens of traps recommended to be deployed in a typical Illinois corn field: by late July the densely planted corn is tall, and it is difficult to walk the rows of a large field. This discourages on-site monitoring of farms for this pest, resulting in over-application of insecticides and other controls.

We propose to automate the inspection of planar insect traps with an inexpensive grid of computer-controlled sensors, each communicating with a base station through a radio link. Each sensor station would include a radio-capable microcontroller, a medium resolution camera, a GPS receiver, and sensors to measure temperature, atmospheric pressure, relative humidity, and airborne volatile organic compound concentrations. A small photovoltaic cell would recharge the station's battery during daylight hours. It should be possible to interrogate each station a dozen times per hour.

The recent rise of a do-it-yourself "maker culture" has opened a significant market to manufacturers of inexpensive microcontrollers and sensors. We hope to take advantage of this, and will discuss the cost per station in the body of our proposal. We are requesting support to build a proof-of-concept system with three stations and one base station.

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[3] See, for example, U.S. Environmental Protection Agency, "EPA Registers Innovative Tool to Control Corn Rootworm," June 15, 2017, available at https://www.epa.gov/newsreleases/epa-registers-innovative-tool-control-corn-rootworm, and J. Tollefson Levine et al., "Management Guide for Corn Rootworms," https://www.ent.iastate.edu/pest/crwhmpg/crwmng.html, visited January 12, 2020.

Project description

a. Project significance

The current lack of a reliable, cost-effective tool for monitoring western corn rootworm populations represents an economic limitation to Midwestern corn producers. Western corn rootworm is the most expensive insect pest of corn in the U.S. by far, costing farmers over $1 billion each year in yield losses and control costs.[4] Monitoring techniques for this insect have changed little since the mid-1980s:[5] the farmer or a scout must place yellow sticky cards (which attract and arrest the beetles) throughout the field and inspect them weekly for 3-5 weeks during late summer to make a control decision at planting the following spring. This practice is simply untenable to most commercial operations due to the associated labor costs. Without access to field-specific monitoring information, farmers in the northern two-thirds of Illinois (as well as most of the western and northern U.S. Corn Belt) typically default to applying a rootworm control (either a soil insecticide or a hybrid with a biotech resistance trait) with an associated cost of roughly $15 per acre.[6] In addition to the environmental and resistance management costs of unnecessary control decisions, this expense has no associated return to the farmer in those fields that do not have a damaging population of corn rootworm.

We propose to build a demonstrator system of inexpensive sensor stations that will photograph the surfaces of planar adhesive insect traps several times per hour. The stations will transmit the images and other environmental (and geographical) data to a base station for further processing and analysis. Within financial constraints, the measuring stations can be deployed as densely as desired, increasing the likelihood that emerging beetles can be detected before they begin laying eggs.

Equipped with cameras, GPS receivers, and radio-capable microcontrollers, the placement of individual stations is flexible, and can be changed during the growing season as necessary to increase sensor density wherever it is appropriate. It is conceivable

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[4] Tinsley, N. A., P. D. Mitchell, R. J. Wright, L. N. Meinke, R. E. Estes, and M. E. Gray. 2016. Estimation of efficacy functions for products used to manage corn rootworm larval injury. Journal of Applied Entomology 140: 414-425 and Wilson, T. A., M. E. Rice, J.J. Tollefson, and C. D. Pilcher. 2005. Transgenic corn for control of the European corn borer and corn rootworms: a survey of Midwestern farmers' practices and perceptions. Journal of Economic Entomology 98: 237-247.

[5] Hein, G. L. and J. J. Tollefson. 1985. Use of the Pherocon AM trap as a scouting tool for predicting damage by corn rootworm (Coleoptera: Chrysomelidae) larvae. Journal of Economic Entomology 78: 200-203.

[6] Crowder, D. W., D. W. Onstad, M. E. Gray, P. D. Mitchell, J. L. Spencer, and R. J. Brazee. 2005. Economic analysis of dynamic management strategies utilizing transgenic corn for control of western corn rootworm (Coleoptera: Chrysomelidae). Journal of Economic Entomology 98: 961-975 and Mitchell, P. D., M. E. Gray, and K. L. Steffey. 2004. A composed-error model for estimating pest-damage functions and the impact of the western corn rootworm soybean variant in Illinois. American Journal of Agricultural Economics 82: 332-344.

that more information, both more finely grained and more frequently recorded, might allow reductions in both crop loss and pesticide usage through precision targeting of infestations. Our proposal lays the foundation for automated monitoring of the most economically important insect pest of corn in the U.S., and is aligned with the Automation theme area of the Center for Digital Agriculture

b. Investigators

The proposal's principal investigators are Professor George Gollin (Physics), an elementary particle experimentalist with extensive experience in design and construction of distributed systems of instrumentation, and Research Assistant Professor Nick Seiter, an entomologist whose research includes studies of corn rootworm suppression. Their biographical sketches are attached to this proposal.

c. Innovation

The proposed system's most innovative features are

- its flexibility: sensor stations can be deployed in a regular or irregular array that can be reconfigured during the growing season as suggested by analysis of incoming data, nearly in real time;
- the rate at which it can be interrogated: data can be pulled from sensor stations as frequently as desired; interrogating each station a dozen times per hour is feasible;
- its specificity: optical recognition and classification of trapped pests through basic machine learning techniques should be possible;
- its low cost: the availability of inexpensive sensors and microcontrollers, in response to a growing do-it-yourself "maker culture" market, makes feasible a low cost-per-station;
- its extensibility and scalability: software improvements and the possibility to retrofit additional sensors will permit the extension of a sensor station's capabilities, while the 1 km range of a station's 900 MHz radio will allow a single base station to communicate with stations scattered over a 1,000 acre area.

d. Approach and future potential

The basic unit of the system will be a pole-mounted sensor station. The components in one station are likely to be

- a photovoltaic cell
- rechargeable battery
- a 900 MHz radio-capable microcontroller
- a GPS receiver
- a 640 × 480 (color) digital camera

- a real time clock and a temperature/pressure/humidity/volatile organic compounds module
- a microSD card read/write device
- mounting hardware

We list suitable devices in the budget, below.

We do not see any fundamental technical barriers to scaling the system to cover a 1,000 acre farm with several sensors per acre. From our initial studies we hope to understand the issues (if any, other than cost) of deploying a dense, very large system at "enterprise scale."

We believe that this project can serve as an excellent multi-disciplinary training exercise for students in both physics and crop science. These students would have the opportunity to (1) develop the prototype system and (2) test its functionality in a field situation.

The development of this system would be the catalyst for numerous applied research questions related to its implementation in commercial field settings, including:

- Are trapping results achieved using the improved system comparable to those achieved using traditional methods?
- What improvements in predictive value of trapping are possible given the potential increase in sample density of the improved system?
- What are the economic returns of monitoring-based rootworm control decision-making using this improved system, compared with the current framework of preventative control?
- How can this system be modified to automate monitoring of other insect pests?

A natural potential funding source for larger projects to answer these questions would be the USDA Agriculture and Food Research Initiative's Foundational and Applied Science Program, which includes the Pest and Beneficial Species in Agricultural Production Systems program area. In addition, the functioning demonstrator system would be a candidate for commercial development through the Center for Digital Agriculture's Industrial Affiliates program.

e. Environment

The environmental impact of the solar-powered stations will be minimal. Since the information obtained might allow a reduction in the use of pesticides, we hope to see significant environmental benefits to its deployment at scale.

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1. U.S. Environmental Protection Agency, "EPA Registers Innovative Tool to Control Corn Rootworm," June 15, 2017, available at https://www.epa.gov/newsreleases/epa-registers-innovative-tool-control-corn-rootworm.

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3. Christina Welch Stair et al., "An Economic Analysis of Corn Rootworm Management," *American Agricultural Economics Association Annual Meetings,* Tampa, Florida, July 30 – August 2, 2000.

4. Tinsley, N. A., P. D. Mitchell, R. J. Wright, L. N. Meinke, R. E. Estes, and M. E. Gray, "Estimation of efficacy functions for products used to manage corn rootworm larval injury," *Journal of Applied Entomology* 140: 414-425, 2016; Wilson, T. A., M. E. Rice, J.J. Tollefson, and C. D. Pilcher, "Transgenic corn for control of the European corn borer and corn rootworms: a survey of Midwestern farmers' practices and perceptions," *Journal of Economic Entomology* 98: 237-247, 005.

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6. Crowder, D. W., D. W. Onstad, M. E. Gray, P. D. Mitchell, J. L. Spencer, and R. J. Brazee, "Economic analysis of dynamic management strategies utilizing transgenic corn for control of western corn rootworm (Coleoptera: Chrysomelidae)," *Journal of Economic Entomology* 98: 961-975, 2005; Mitchell, P. D., M. E. Gray, and K. L. Steffey, "A composed-error model for estimating pest-damage functions and the impact of the western corn rootworm soybean variant in Illinois," *American Journal of Agricultural Economics* 82: 332-344, 2004.

Budget and budget justification

We hope to build a three-station (plus base station) proof-of-concept system. The proposed investigation offers excellent interdisciplinary pedagogical possibilities, so we seek funds to hire two Physics undergraduates and one Crop Sciences undergraduate to work with us as summer research assistants.

The budgeted items for a sensor station will allow it to function autonomously, without human intervention, for much of the growing season. The inclusion of GPS capabilities permits each station to report its precise location after installation in a field, and after any adjustment of its position. More information, serving as justification, appears with each item listed.

Cost of one sensor (or base) station:

N	items for one sensor station (same for base station except for camera)	price
1	ALLPOWERS 2.5W 5V solar cell (recharges station's battery)	9.
1	Adafruit Feather M0 microcontroller with RFM95 LoRa Radio (processor controlling the system and communicating with base station processor)	32.
1	Adafruit Ultimate GPS breakout (provides geographical location data)	33.
1	Adafruit TTL JPEG camera, 640 × 480 (images the insect traps)	33.
1	Adafruit BME680 T/P/RH/VOC sensor breakout (measures environmental parameters: temperature, pressure, humidity, airborne volatile organics.)	18.
1	Adafruit DS3231 real time clock (maintains UTC time even when system is unpowered)	13.
1	Adafruit microSD card breakout (onboard backup data storage)	7.
1	Lithium ion battery, 3.7V, 2000 mAh (provides power for microcontroller)	12.
1	3D-printed enclosure (protects components from rain and hail)	5.
1	mounting pole and associated hardware (sensors and camera need to be several feet above the soil)	15.
1	printed circuit board (holds the components, provides interconnects)	10.
	total	187.

System hardware cost

N	items for complete demonstrator system	price
1	printed circuit board fabrication one-time setup charge (charged by PCB fabricator)	100.
3	sensor station @ $187 each	561.
1	base station (queries the sensor stations, receives and stores their data)	154.
1	miscellaneous hardware (nuts, bolts, cable ties, and so forth)	150.
	total	965.

PI summer salaries, ½ month

who	cost
George Gollin	7,000.
Nick Seiter	4,000.
total	11,000.

Summer undergraduate research assistants: 8 weeks, 35 hours per week, $15/hour

N	Undergraduate research assistants	price
3	$4,200 per student	12,600.

Total funds requested: $965 + $11,000 + $12,600 = $24,565.