ACOUSTIC SYSTEM FOR RAPIDLY DETECTING AND MONITORING PINK BOLLWORM IN COTTON BOLLS

Robert Hickling
Sonometrics Inc.
Huntington Woods, MI
Peng Lee and Doru Velea
National Center for Physical Acoustics
University of Mississippi, MS
Timothy J. Dennehy and Amanda I. Patin
Dept. of Entomology
University of Arizona
Tucson, AZ

Abstract

The 32-channel acoustic system described in this paper replaces the cutting method of detecting pink bollworm in bolls. It is shown that the system can detect pink bollworm even in the first instar. Because the system senses all channels simultaneously, it is extremely rapid. Also it is much less labor intensive and significantly reduces the risk of human error. The system can detect all types of insect infestation. It can be used, for example, to inspect fruit and vegetables entering the United States. In addition to detecting infestation, the system can be used in laboratory research, for non-intrusive monitoring of the life cycle of larvae in agricultural commodities, and other host materials. It can also be used for monitoring larvae in the soil. It can operate continuously without human intervention over periods of days, weeks and even months.

Introduction

This paper describes an acoustic system for detecting and monitoring pink bollworm, *Pectinophera gossypiella*. The system has been several years in development. We have demonstrated its usefulness both as a research tool and as practical device to replace the cutting method for detecting larvae in agricultural commodities. Early and accurate detection is critical for controlling infestation of pink bollworm and reducing the use of insecticides.

Essentially the system detects larval activity inside the cotton boll from the sounds made by larvae eating and moving. To do this, sensitive acoustic detectors are required in an environment free from noise interference. Detecting infestation when the bolls are on the plant is fairly impractical. Instead, we seek to replace the existing cut and search procedure for boll samples brought in from the fields, shown in Figure 1.

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Figure 1. Standard cutting procedure for detecting pink bollworm infestation.

Searching a boll takes approximately 20 to 40 seconds. This is tedious, time-consuming and subject to human error. Also it is almost impossible to detect first-instar larvae with unaided vision. Hence the cutting method is a weak link in gathering information about pink bollworm infestation in the fields.

Description of Acoustic System and Results of Preliminary Tests

What we have developed to replace the cutting method is a set of acoustic sensors in a soundproof box. We had first of all to develop an inexpensive sensor that could detect larval activity. We found that a standard electret microphone in a stethoscope head works admirably for the purpose. The cost is about ten dollars. Figure 2 shows the sensor. We have to amplify the signals from the sensor. Then we either listen with earphones or digitize the signals for use in a computer.

Figure 2. Acoustic Sensor.

Originally we used two wooden boxes, one within the other, with sand between, to create a quiet environment. Subsequently we used steel boxes with absorbing material inside. Figure 4 shows the double steel box we built for preliminary tests performed with Dr. Robert Staten,. at the USDA-APHIS Methods Development Center in Phoenix

(Hickling et al., 1994). We crammed as many sensors as possible into the box, together with amplifiers. It contained 48 sensing units about 250 mm high and it took 4 strong men to lift the box.

Figure 3. System used for preliminary tests at USDA-APHIS in Phoenix.

In the tests, a single cotton boll is placed on each sensor and the lids of the boxes are closed. Each sensing unit had an LED that lights if larval activity is detected. Alternatively you can listen with earphones. Dr. Staten's people preferred to use the earphones. In these tests, three procedures were compared: (a) the acoustic method, (b) the cutting method and (c) the boll-box method in which larval exit holes in the bolls are counted. Bolls that were tested with the acoustic method were subsequently cut open to check the method. To increase larval activity, all the acoustically tested bolls were warmed to 38 degrees Celsius internal temperature prior to testing. Figure 4 shows some of the data. 300 bolls, obtained under similar conditions, were tested with each detection method. The number of infested bolls is shown in clear blocks.

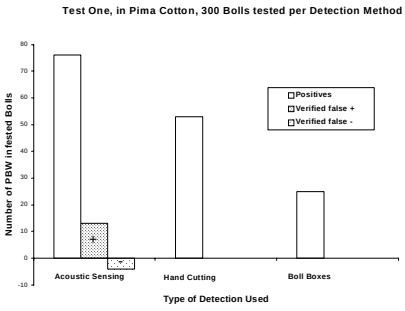

Figure 4. Comparison of different detection methods.

Two additional sets of data similar to Figure 4 were obtained. In all three sets of data, more infested bolls were found by the acoustic method than by the cutting or the boll-box methods. Cutting was used to estimate possible error in the acoustic method. We found some false positives, that is we thought we heard a larva but when we cut the boll we didn't find one. This could be because the larva was a first instar and not readily visible. We also found false negatives; that is, the acoustic sensing did not detect a larva that was later found by cutting. This may be because the larvae were not active when sensing. Also, since earphones were used, there is a possibility of human error. In all three sets of data the acoustic method was found to be more reliable than the cutting and boll-box methods. Also the acoustic method is much faster. This preliminary study was reported at the Beltwide Cotton Conferences in 1994 (Hickling et al., 1994).

Subsequent Work

After these preliminary tests we realized a lot had to be done to make the method more practical. The boxes had to be more portable. We had to improve the electronics and signal processing. And we had to reduce human involvement as much as possible. The system was used for some other applications. Examples of the boxes that were used subsequently are shown in Figure 5. One application for which the method was used was checking the fertilization of emu eggs. Since the shells of emu eggs are opaque, they cannot be tested using standard candling techniques. We were quite successful with this but interest waned when the bottom fell out of the emu market.

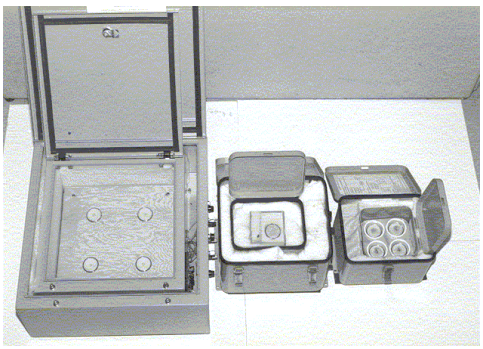

Figure 5. Different types of test systems.

In 1998, we collaborated with Dr. Gadi Forer of the Israeli Cotton Board in practical tests of the system for detecting pink bollworm on a kibbutz. In this version of the system, we divided the number of sensors between 2 boxes, with 16 sensors per box. Also the amplifiers were located outside the box. Thus the boxes were more portable. We also let the computer decide if there was infestation in a boll. This field experience was extremely useful because it showed what improvements were needed. The system was more susceptible to noise interference than we expected both from the amplifiers and from ambient noise disturbance, such as from air-conditioning, or a passing truck or aircraft. Also the sensors were operated in sequence and hence the system was 32 times slower than it might have been.

We spent the next year remedying these defects. We developed an amplifier that was much less noisy. Also new computer boards became available that made it possible to input the 32 channels simultaneously. Finally we developed new software to analyze the data. Figure 6 is a schematic and Figure 7 is a photo of the new system.

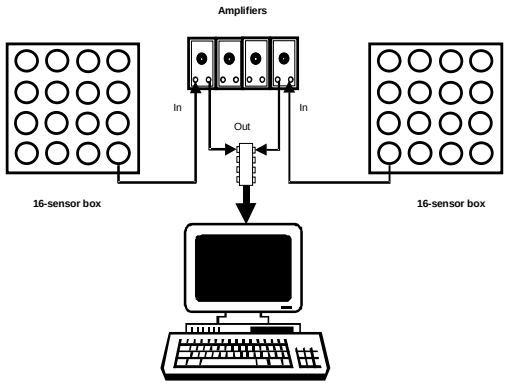

Figure 6. Schematic of the 32-channel system.

Figure 7. Photograph of the 32-channel system.

Use of the System for Laboratory Research

Since the new system can run continuously, we realized that, as well as developing a means of detecting larval activity, we had developed a research tool to study the life cycle of larvae in agricultural commodities and other host materials. For example, we studied the life cycle of the larva of the rice weevil, *Sitophilus oryzae*, in grain (Hickling at al., 1999). The larva pupates as well as molts inside the grain and emerges as an adult. The system software measures the activity of the larva by determining the number of acoustic events per minute, as a function of time in days, as shown in Figure 8. Activity is low during the first instar, picking up gradually. Then it enters into a brief period of quiescence when the larva molts or sheds its skin. After the first molt, activity picks up again till the next molt and then again to the third molt, after which the larva prepares to pupate. The pupation period is much longer than the molt period and there is a more activity during pupation than during molting.

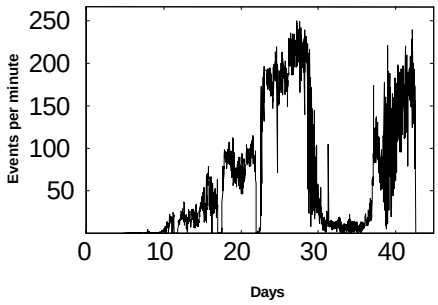

Figure 8. Acoustic monitoring of the life cycle of the rice-weevil larva in grain.

The activity peak shortly after the beginning of the pupation period is where the larva sheds its skin before becoming a pupa. After pupation the adult eats its way out of the grain. Since 32 samples are obtained simultaneously with the system, we can make statistical studies of the life cycle. We have also studied the life cycle of the larva of the Caribbean fruit fly, *Anastrepha suspensa* (Loew) (Velea et al.,1999). In this case the larva emerges and pupates in the soil. The life cycle of other larvae can be studied in the same way. We showed that we could detect first-instar activity quite clearly for both the rice weevil and Caribbean fruit fly.

One of the major advantages of the system is that it can be operated while the researcher is doing other things, like teaching, writing proposals and attending meetings. Currently we have 3 systems operating while we are at the meeting in San Antonio.

Continuation of Pink Bollworm Studies

Having demonstrated the effectiveness of the system for laboratory research, we returned to the practical problem of detecting pink bollworm. Unfortunately we were not able to go to Israel this past summer but we plan to do so in future. However we were able to spend some time at the University of Arizona working with Dr. Tim Dennehy. We are particularly indebted to Amanda Patin who went to great lengths to provide us with bolls infested at different stages of development. We had 2 objectives: (a) to show that our software could detect first-instar larvae; and (b) to follow the life cycle of the pink bollworm as we had done for the rice weevil (Hickling at al., 1999) and fruit fly (Velea et al., 1999). We hoped to obtain the kind of information about the life cycle of pink bollworm obtained previously by others (Watson and Johnson, 1974), except that our method was a non-intrusive procedure with bolls. We were successful in achieving the first objective but not the second.

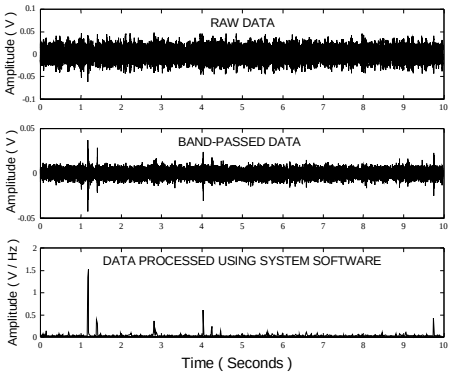

Figure 9. Detection by system software of first instar larva of pink bollworm.

Figure 9 shows a segment of first instar data. The first trace is the raw data from the sensor. The ear is capable of picking out larval activity signals even though they are obscured by noise (as demonstrated at the meeting by playing a tape). In the second trace, elementary band-pass filtering is applied between 350 and 650 Hz to remove low and high frequency components of noise. This reveals the larval activity signals that were detected by the human ear in the raw data. The third trace results from applying the processing used in our software, which consists of a proprietary frequency-domain analysis. In this trace, the larval activity signals detected by the human ear in the raw data appear quite clearly. This last trace is the data used to determine the number of acoustic events per minute as a function of time, as in Figure 8. We thus can detect first-instar activity for the pink bollworm, as we had previously for the rice weevil and Caribbean fruit fly.

However we were not able to obtain sufficient data on the life cycle of the pink bollworm in the boll because the time we could spend in Arizona was limited. Also noise interference proved to be more of a problem than we had anticipated, particularly for continuous testing over a period of days.

Additional Methods of Reducing Noise Interference

The tests in Arizona indicated that additional methods of reducing interference due to ambient noise and vibration were needed if the system was to be used in practical tests. Two methods are under development. The first involves the use of constrained-layer damping to reduce resonant vibrations in the steel boxes. Figure 10 shows a box covered with damping material. A significant reduction in noise interference was achieved in this way.

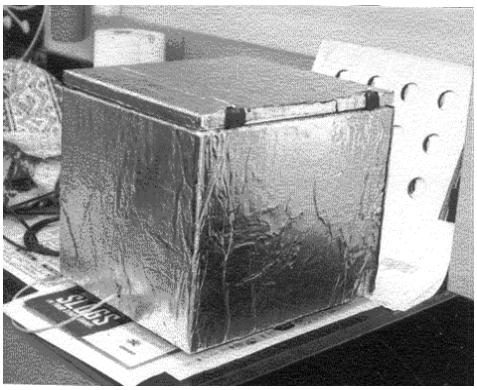

Figure 10. Layer of constrained-layer damping on outside of steel box.

The second method involves the use of an additional enclosure containing the two steel boxes. This enclosure could take different forms. It could be an additional box enclosing the first two boxes, or it could be a special isolated space dedicated to acoustic testing, even a special room.

Conclusion

The 32-channel system described in this paper is a powerful tool, both for laboratory research and as a replacement for the cutting method of detecting larvae in agricultural commodities. It can detect pink bollworm in bolls during the first instar. Simultaneous sensing on many channels makes the system extremely rapid. Also the system is cost–effective and greatly reduces the risk of human error.

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