Can Honey Bees Assist in Area Reduction and Landmine Detection?

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Honey bees have recently received considerable attention from the popular press as an innovative method to detect a variety of explosives, landmines and UXO. Many of these reports are inaccurate and may encourage individuals and demining groups to "sell" a service that they poorly understand or lack the experience to properly apply. As the developers of this technology, we offer the following summary about the current status of this alternative for landmine detection, including its strengths and limitations.

by Jerry J. Bromenshenk, Collin B. Henderson, Robert A. Seccombe, Dwayne D. Rice and Robert T. Etter, Bee Alert Technology, Inc. and UM; Susan F.A. Bender and Philip J. Rodkey, SNL; Joseph A. Shaw, Nathan L. Seldomridge and Lee H. Spangler, MSU; and James J. Wilson, NOAA

Background

People and bees have a long and mutually beneficial history. Ancient cave paintings in Spain depict a woman harvesting honey. The Egyptians moulled bees on hoops up and down the Nile. Originating near current-day Afghanistan, one species of honey bee, Apis mellifera, now lives all over the world, with the exception of the Antarctic and far Arctic regions. In every community and country, bees are kept for the honey and wax that they produce, and for the crops that they pollinate.

Passive Sampling

More than 30 years ago, we at the University of Montana (UM) began sending out bees to explore and sample environments of interest, as a way of collecting and mapping data over large areas, even across large cities. A honey bee's body has branched hairs and they produce protective layers of air and bring back water for evaporative cooling of the hive. As such, bees sample all media (air, soil, water and vegetation) and all chemical forms (gaseous, liquid and particulate). With proper colony placement and sampling, gradient maps of the distribution of chemical or biological materials can be produced.

This approach has been described in numerous studies and publications, with statistical mapping of large areas first described by us in Science, 1985. Other investigations, especially in Europe, have confirmed our approach, with a monograph covering this topic appearing in 2002. Although all of the authors agreed upon the effectiveness and utility of bees, some had difficulty attributing or correlating the chemicals found in or on bees, pollen, honey or the hive with potential sources in the environment. Time of year, spatial distribution of the colonies, and components of the hive to be sampled all must be considered before an appropriate sampling plan can be developed and carried out. Simply taking "grub" samples or pulling honey jars off the shelf is not likely to show anything other than that same material is present or not present.

Given an appropriate sampling design, bees can quickly provide samples of materials in the vicinity of each hive, since the foragers from each colony will make tens to hundreds of thousands of foraging forays or flights each day, with each forager returning to its home hive by nightfall. This passive collection to determine environmental presence of chemical and biological threats can provide an initial survey of landscapes. Generally, it identifies regions where materials of concern can be found and, with appropriate correlation of sites and re-sampling, can help narrow down the search to areas of a few hundred meters.

Active Training and Search

For more than four years, we have been refining our ability to condition or train bees to travel to areas of interest. Bees have an acute sense of smell and can be trained to find explosives, bombs and landmines, as well as other chemicals of interest, including drugs and even decomposing bodies.

Under contract from the Defense Advanced Research Project Agency’s (DARPA’s) Controlled Biological and Biometric Systems Program, we developed the methods and technology necessary to condition bees to pass rigorous blind field trials, conducted at Southwest Research Institute in San Antonio, Texas, Sandia National Laboratory (SNL) and the Air Force Research Laboratory (AFRL) in collaboration with our work, providing specific expertise in explosives and signal processing, respectively.

Through a series of repeated trials conducted in 2001 and 2002, we observed that bees behaved like a very fine-tuned, nearly ideal detector at vapor levels higher than 10 ppb from 2,4-dimethylsquioxane (2,4-D) mixed in sand. In 2001 and 2002, AFRL and we calculated a detection probability of 97.99 percent per part per billion (ppb) and parts per trillion (ppt) vapor concentrations, less than one percent false probability of false positive and less than one percent false probability of false negative. In the 2002 tests, bees consistently detected 2,4-D at concentrations of 50-80 ppm vapor. Under more difficult conditions, this dropped to about 50 ppt. AFRL predicted that with sufficient numbers of bees, the detection threshold could go even lower.

Bees are trained in much the same way as dogs, using traditional operant conditioning methods. The reward is food, which is associated with the odor of the chemical of interest. Like dogs, bees can detect traces of chemical such as 2,4-DNT, 2,6-DNT, TNT and RDX over a wide range of concentrations. Bees indicate the presence of an odor by the number of bees following and "grabbing" toward and above a source or target. We have observed that bees detect the vapor plume several meters from the source, then navigate up the plume to the source. Numbers of bees over odor sources are integrated over time and compared to those over the rest of the area. In other words, we map the density of bees over, for instance, visual, camera- or laser- assisted sources.

By the end of our DARPA contract in August 2002, we had convincing evidence that bees could reliably find explosives at levels reported to occur in landmine fields. However, we still had to demonstrate that honey bees could detect real landmines at a well-characterized minefield. Furthermore, in order to demonstrate that the bee concept was useful, we also had to show that we had a means of detecting or tracking bees at a distance from the hive and over the landmines.

We were concerned that bees might have problems when faced with multiple chemical sources in an area. Would the bees go to the highest vapor sources and ignore others? We also needed to be able to find bees at distances consistent with their long-range flight ability. Visual observations and cameras were suitable only for short-range trials or for simulated trials where the observer could readily walk out into the field.

Since bees can easily fly up to three to five km, it was highly desirable to have a bee detection system that could cover that same range, both from the standpoint of realizing the full potential of bees for dramatically reducing the time required to survey an area and from the aspect of personnel safety.

Ft. Leonard Wood Landmine Trials, Summer 2003

SNIK Electronics (SKE), UM and Montana State University (MSU), in collaboration with the National Oceanic and Atmospheric Administration’s (NOAA’s) Environmental Technology Laboratory and SNL, funded and conducted a blind field test at the Ft. Leonard Wood minefield from July 25 to August 5, 2003. Tests were conducted to determine whether conditioned honey bees could be used to locate buried landmines and explosives, MSU and NOAA joined in with the Light Detection and Ranging (LIDAR) technology for this demonstration.

UM’s earlier trials had demonstrated that honey bees can be trained to efficiently and accurately locate explosives signatures in the environment. However, it was difficult to track bees and determine precisely where the targets are located. Video equipment is not practical due to its limited resolution and range. In addition, it is often unsafe to set up cameras within a minefield.

Earlier tests by SNL had demonstrated that a LIDAR system could see bees (patent pending), but did not show that a LIDAR system could detect and track bees at a distance from the hive and over the landmines.

LIDAR is a remote sensing technique that uses laser light in much the same way that sonar uses sound or radar uses radio waves. Laser light pulses are transmitted over the area where bees are trained to fly. Some of the laser light that strikes the bees is scattered back to a detector collected with the laser. The time between the outgoing laser pulse and the return signal is used to measure the distance to the bees to the LIDAR. By using a narrow laser beam and scanning this beam over time, one can produce an accurate map of the location of the bees. Since LIDAR can provide both the range and the coordinates of the bees over targets, the location of buried munitions can be mapped for subsequent removal.

Bees, dust and hard objects produce a backscatter signal that is larger than the typical atmosphere. Whereas it is possible to discriminate different objects with fluorescence LIDAR, for this test we simply compared the density of bees over the minefield and an adjacent control area. Other insects may have been detected, but their numbers were small compared to the bees.

SNIK also conducted vapor plume and soil sampling, followed by chemical analysis for explosives, to verify bee localization of mines. All results were submitted to the Army’s Night Vision Laboratory for final assessment of bee performance.

The objectives for the Ft. Leonard Wood trials were:

1. Show that area reduction (i.e., discrimination of mined versus unmined areas) can be performed by conditioned bees.
2. Show that bees can locate individual mines or at least small clusters of mines.
3. Demonstrate that LIDAR can be used as an effective tool for mapping density (number) of conditioned bees focused on explosive vapors emitted from buried mines.

Ten full colonies of bees were conditioned to search for explosive vapors. The conditioning method developed by UM during the previous three-year...
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Darpa-funded research was used for these trials. All of the um methods and equipment have patents pending and have been licensed to See and Bee Alert Technology, Inc. To demonstrate that bees can find mines, we employed:

1. Video cameras focused on selected possible mine locations and blank areas within the minefield and an adjacent unmined area.
2. Visual counts of bees within the minefield.
3. Intercepts of bees traversing the minefield and the adjacent unmined area. Each of these methods accumulated counts of bees over specific locations on and off the minefield.

The deployment employed a NOA LIDAR system that swipes the field every second. Bee conditioning was accomplished using a new, pressured, digitally controlled (hands-off) bee conditioning system, developed and tested by UM under private industry funding in California during the spring of 2003.

Results of Ft. Leonard Wood Bee Trial Trials

All of the data forms (LIDAR, video, visual counts) indicate that area reduction, identification, and ranking (strength of the plume source) could be determined using bees. The following are some results of the trials:

1. LIDAR was able to detect individual bees at long ranges of hundreds of meters. Fixed and variable modes were tested and proved capable of providing bee location and range data within a few centimeters accuracy.
2. Video and visual counts showed that bees found both individual mines and clusters of mines within the test area.
3. Preliminary chemical analyses results indicate that numbers of bees correlate with plume concentrations. Ten of 12 vapor sources identified by the initial chemical analysis have already been detected by a partial data set of bee counts (based on only four days of the data). The contour maps of the landfield, based on the visual and partial video counts of bees and on the cumulative results of three different chemical sensing methods, illustrate the degree of localization that was achieved.

4. In the designated, unminted, blank or control area, the LIDAR detected a concentration of bees over a spot in front of the minefall. When that spot was later sampled, it was found to be contaminated with TNT, 2,4-DNT and 4-amino-DNT.
5. The pressurized conditioning system worked flawlessly, and Montana bees conditioned as readily as any of the bees that we have previously worked with in Montana and Texas.
6. The bees also made a surprise detection of a contaminated site where none was expected. This example proves the importance of combining a high-resolution tracking system such as LIDAR with properly conditioned bees as a system for detecting explosives or residues.

Conclusions and Recommendations

The Ft. Leonard Wood trials demonstrated both area reduction and localization of vapor plume source within the mined area. The deployment of a fieldable, stand-alone conditioning system was also successfully demonstrated. When used in accordance with specific protocols, active conditioning and target detection were maintained for several days with a small, static set of colonies, demonstrating the proficiency of this system. Some work remains in optimization of the engineering and conditioning protocols and for designing a portable tracking system.

LIDAR tracking and mapping of bee densities or distributions not only worked, but also located bees over a heretofore unknown source of explosives in the supposedly control area. The LIDAR used for these trials was developed for surveying fish, not bees. MSU's goal is to produce a low-cost, lightweight, suitcase-sized, field-portable optimized LIDAR system for bee detection.

With appropriate funding, we should be able to field proof a readily deployable system at minefield and UXO locations in the United States, in Canada and overseas in 18 months. Following the experience and fine-tuning of the system through field trials at other locations, deployment could rapidly scale.

We do not expect bees to replace dogs. Rather, we anticipate that bees, in passive and active modes, could be used in concert with dogs and other methods to reduce the time and expense of area reduction and landmine field surveys.

Like dogs, bees are able to recognize multiple substances concurrently at very low concentrations. To date, we have trained bees on the odors of the main charge explosive, but we could also include casing materials (plastic, rubber, cardboard, wood, paint). Including other materials might improve performance, especially if there is no odor from the main charge. As with any vapor sensing system, bees cannot find a mine that is not leaking. We also see the need for additional research to define the performance of mine-detecting bees, taking into consideration environmental factors that influence the amount of chemical signatures.

A critical humanitarian demining issue is the amount of arable land that has been mined; putting agricultural fields back into production is a major objective. War often disrupts and sometimes destroys bees. Inactive and beekeeping. The first step in economic development often focuses on re-establishing beekeeping, since bees are essential to the pollination of many crops and agricultural productivity. Use of honey bees for humanitarian demining addresses both issues—clearance of crop lands and protection of beekeepers and agriculture.