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Can Honey Bees Assist in Area Reduction and Landmine Detection?

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.

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Bee deployment at Fort Leonard Wood.

Background

People and bees have a long and mutually beneficial history. Ancient cave paintings in Spain depict a woman harvesting honey. The Egyptians moved bees on barges 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 within a two-to-four-km radius of the hive. A honey bee's body has branched hairs that develop a static electricity charge, making them an extremely effective collector of chemical and biological particles, including pollutants, biological warfare agents and explosives. They also inhale large quantities 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.[1] Other investigators, especially in Europe, have emulated our approach, with a monograph covering this topic appearing in 2002.[2] 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 "grab" samples or pulling honey jars off the shelf is not likely to show anything other than that some material of interest is or is 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. It generally identifies regions where materials of concern can be found and, with appropriate re-location of hives 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 go to "odors 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.[3]

Begun under a contract from the Defense Advanced Research Project Agency's (DARPA's) Controlled Biological and Biomimetic Systems Program, we developed the methods and equipment necessary to condition bees to pass rigorous blind field trials, conducted at Southwest Research Institute in San Antonio, Texas. Sandia National Laboratories (SNL) and the Air Force Research Laboratory (AFRL) collaborated in 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 pptr from 2.4-dinitrotoulene (2.4–DNT) mixed in sand. In 2001, AFRL and we calculated a detection probability of 97-99 percent at parts per billion (ppb) and parts per trillion (pptr) vapor concentrations, with a 1.0–2.5 percent probability of false positive and less than one percent false probability of false negative.[4] In the 2002 tests, bees consistently detected DNT targets generating 50–80 pptr vapor. Under moist conditions, this dropped to about 30 pptr. 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 suites 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 numbers of bees following vapor plumes toward and over the 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 an area, using visual, camera or laser-assisted counts.

By the end of our DARPA contract in August 2002, we had convincing evidence that bees could reliably find explosives' vapors 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 Trial, Summer 2003

S&K 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 can 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 could track bees. Nor did the tests make scanning LIDAR measurements.

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 collocated with the laser. The time between the outgoing laser pulse and the return signal is used to measure the distance from 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 back-scatter 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 those of the bees.

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

The objectives for the Ft. Leonard Wood tests were to:

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 (numbers) of conditioned bees focused on explosive vapors emitted from buried mines.

Ten full-size 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 SKE 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.

Also employed was a NOAA LIDAR system that swept the field every 26 seconds. Bee conditioning was accomplished using a new, pressurized, 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 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:

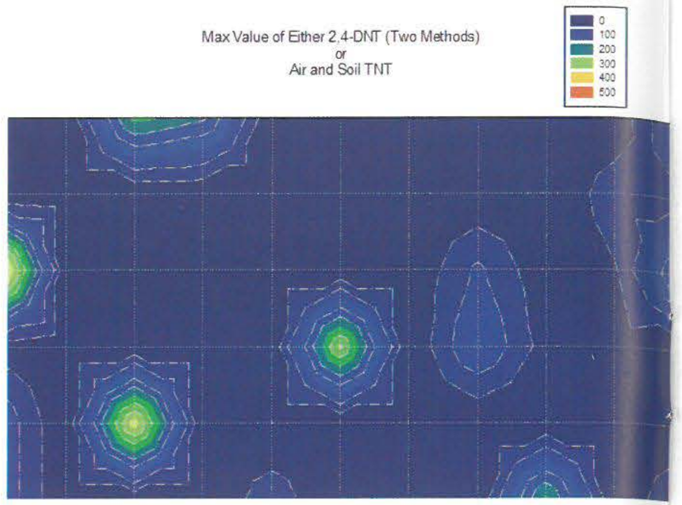
1. LIDAR was able to detect individual bees at long ranges of hundreds of meters. Fixed and scan modes were tested and proved capable of providing bee location and range data within a few centimeters' resolution.

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 landmine field, based on the visual and partial video counts of bees and on the cumulative results of three different chemical sampling methods illustrate the degree of localization that was achieved.

4. In the designated, unmined, blank or control area, the LIDAR detected a concentration of bees over a spot in front of the minefield. 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 Missouri bees conditioned as readily as any of the bees that we have previously worked with in Montana and Texas.



Chemical map of a minefield.

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 sources within the mined area. The deployment of a field-capable, stand-alone conditioning system also was 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 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, light-weight, 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 occur.

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.

Of great concern to us is the need to properly train and certify anyone who intends to use bees in minefields. We believe that training, certification and licensing (similar to that of the Geneva International Center for Humanitarian Demining for dogs) is essential. Toward that end, Bee Alert Technology Inc. in cooperation with the College of Technology of UM, has established programs to provide the necessary training and certifications.

Limitations and Agricultural Benefits

Bees do not fly at night, during heavy rain or wind, or when temperatures drop to near or below freezing. As such, the use of bees is seasonal in temperate climates. Bees are active year-round in tropical regions. These limitations are not unique. Dogs do not perform well in wind, rain or frozen ground, and dogs and handlers usually do not work in the dark. Unlike dogs, bees do not need to bond to their handlers, and they work whenever weather conditions permit. At a weight of one-tenth of a gram, bees are not going to trip wires or set any mines off. Their wide foraging range offers the possibly of greatly speeding up survey times, while also increasing handler safety. Bee colonies can be established along the perimeter of the minefield, not in the minefield. With no leash to hold, the beekeepers can stay well clear of the dangerous area.

Bees have several advantages in addition to their keen sense of smell and wide area coverage:

1. Bees can be conditioned and put into use in one to two days.

2. Local bees and beekeepers are used.

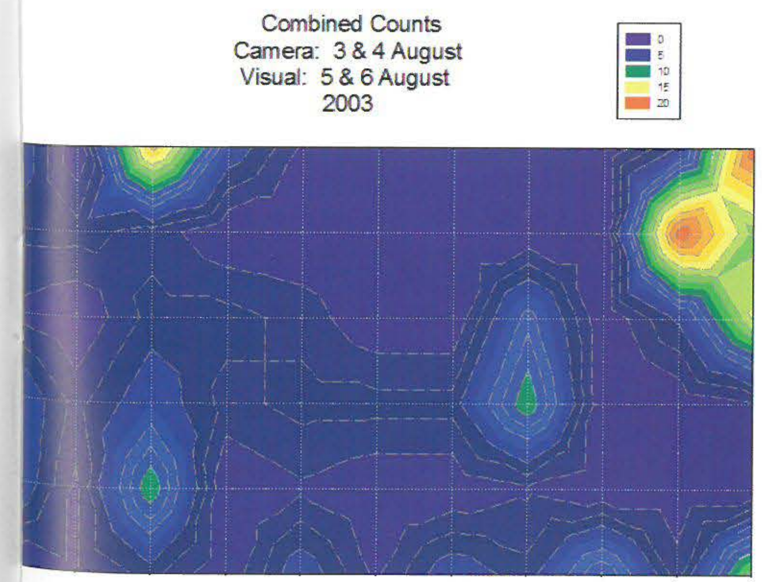
3. Overall costs are far lower than for dog teams.

4. Bees are essential to revitalizing agriculture in war-torn countries.

We have resisted suggestions that we select for genetically superior lines or bioengineer a better honey bee for landmine detection. Because of the prevalence of mites, small hive beetle, and Africanized bees in the United States and many other areas, imports of bee colonies are more or less banned by most countries. Only Hawaii and the south island of New Zealand enjoy relatively unrestricted shipments to other countries.

The best strategy is to make the methods simple and usable by any beekeeper with any honey bees, anywhere in the world. Whether the beekeeper uses sophisticated equipment or keeps bees in a hollow log is of little consequence. It is the knowledge of the beekeeper about his or her bees and area that is important. We can train beekeepers to use our micro-processor controlled food delivery and conditioning systems or a decidedly simpler system, using mine-contaminated soils, conditioning syrup and a squirt bottle. If necessary, binoculars or simple video cameras suspended from a boom or wire can provide short-distance (within yards) observations of bees.

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, beehives 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 croplands and restoration of beekeeping and agriculture.



Bee-generated map of a minefield.

All graphics courtesy of the author.

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