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Title	The use of airborne ultrasound for Varroa destructor mite control in beehives
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Publication date	2018-10-01
Original Citation	Barry, B. C., Verstraten, L., Butler, F. T., Whelan, P. M. and Wright, W. M. D. 'The Use of Airborne Ultrasound for Varroa Destructor Mite Control in Beehives'. 2018 IEEE International Ultrasonics Symposium (IUS), Kobe, Japan, 22-25 October. doi: 10.1109/ULTSYM.2018.8580160
Type of publication	Conference item
Link to publisher's version	https://ieeexplore.ieee.org/abstract/document/8580160 - 10.1109/ULTSYM.2018.8580160
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Download date	2026-11-01 13:08:29
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The use of airborne ultrasound for *Varroa destructor* mite control in beehives

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***Abstract*— The declining health of honey bee (*Apis mellifera*) populations is of global concern, as they are arguably the most important pollinator insect. The *Varroa destructor* mite weakens bees by sucking their haemolymph and spreads debilitating illnesses such as Deformed Wing Virus. Current methods of *Varroa* mite control are usually pesticide-based with potential side effects for the bees or the beekeeper, and can leave residues in the honey or wax. The mites can also develop resistance to these pesticides. The objective of the current work is to investigate the use of high-frequency, high-intensity airborne ultrasound to control the *Varroa* mite populations using a chemical-free technology. A prototype ultrasonic system that generates airborne ultrasonic waves at different frequencies and intensities was constructed and tested. In initial studies, small transparent enclosures were used to observe directly the effects of the ultrasound on the bees. Preliminary in-hive tests were then conducted. Bee hives with varying levels of *Varroa* mite infestation were temporarily sealed to prevent bee traffic and then the bees inside were exposed to the ultrasound. The mite drop from the hive was recorded for (i) 30 minutes before, (ii) during 30 minutes of ultrasound exposure, and (iii) 30 minutes after ultrasonic treatment. The bees in the transparent enclosures exhibited normal behavior and appeared to be unaffected by the ultrasound. Preliminary results from the in-hive experiments indicate a significant increase in the rate of *Varroa* mite drop after only 30 minutes of exposure to the airborne ultrasound inside some of the hives, with the effect continuing after the ultrasonic system was switched off. Long-term field trials of ultrasonic in-hive systems are ongoing.**

Keywords—airborne ultrasound, Varroa destructor mite, bee hive health, chemical-free control, mite removal

I. Introduction

Bees play a critical role in agriculture and food development in the pollination of crops, which is vital for large global agricultural economies and the human food chain. The value of pollination to the world economy has been estimated at more than €155 billion per year [1]. Bees are arguably the most important group of pollinator insect with honey bees (*Apis mellifera*) being the most significant [2], but there is a worldwide decline in honey bees. While beekeeping has declined, data indicate the numbers of bee colonies have increased by 45% in the last 50 years [3], but the rate of colony increase does not match the rate of increase (300%) in pollinator dependent crops [4]. There are currently approximately 90 million bee hives worldwide [5], and at least 76% of European food production and 84% of cultivated vegetable species are dependent on bees for pollination [6]. Pollination by managed honey bee colonies adds at least US$15 billion to the value of US agriculture annually through increased yields and superior-quality harvests [7]. It is also estimated that pollinators, especially honey bees, contribute at least €22 billion annually to the European agriculture industry [8]. It is estimated that there are currently more than 2.4 million managed honey bee colonies in the USA, two-thirds of which travel the country each year pollinating crops and producing honey and beeswax. More than 1.8 million colonies are used each year in California just to pollinate the state's almond crop [9]. There are more than 13 million managed bee colonies in Europe [10].

In spite of increasing knowledge of methods of beekeeping, the worldwide and local movement of bees, in order to improve honey production and provide crop pollination, has caused entire bee populations to be afflicted by a number of pests and pathogens, but in particular the *Varroa destructor* mite [11], which contributes to the devastating colony collapse disorder (CCD), the exact causes of which are still not yet clear. The *Varroa* mites in particular are thought to weaken the bees by sucking their haemolymph and transmit other diseases such as the debilitating Deformed Wing Virus (DWV) to the hives they infest. A frame from a hive of honey bees with a *Varroa* mite circled is shown in Fig. 1.



Fig. 1 A frame from a hive of honey bees (*Apis mellifera*) with a *Varroa destructor* mite.

This work was funded by a Science Foundation Ireland (SFI) Technology Innovation Development Award, grant number 16\TIDA\3917

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Beekeepers across the globe have identified *Varroa* mites as their single most serious problem causing colony losses today. Current methods of *Varroa* mite removal are usually pesticide-based with corresponding potential side effects for the bees (synthetic pyrethroids) or the beekeeper (organic acids), or leave chemical residues in the honey and wax (Thymol), which may then either prevent the beekeeper from treating the hives at the optimum time for overall *Varroa* mite control (which may occur during full honey production), or it may prevent the beekeeper from marketing their products as chemical-free. The mites are also developing resistance to these pesticides that will eventually render them ineffective.

The main aims and objectives of the current work were to investigate a chemical-free method of *Varroa* mite control based on high-frequency airborne ultrasonic waves. Previous work in this area [12] has concentrated on disrupting the feeding cycle of *Varroa* mites in the hive using airborne ultrasonic waves at frequencies of up to 80 kHz. However, these systems had to be used continuously for at least 40 days, and had varying levels of success. The proposed method in this work was to select a higher ultrasonic frequency that directly agitated the *Varroa* mites, and to use a much shorter exposure time.

The first part of this work was to observe the behaviour of the bees when exposed to high-frequency high-intensity airborne ultrasonic waves. The second part of this work was to develop an in-hive system that could then be used to investigate the efficacy of the technique for long-term control of the *Varroa* mites.

II. Apparatus and Experiments

A. To monitor bee behaviour during ultrasound application

Initial experiments were performed to ascertain if the behaviour of the bees was influenced by the application of airborne ultrasonic waves. These were carried out using the prototype system shown schematically in Fig. 2. An arbitrary waveform generator (TTi TGA12012, Thurlby Thandar Instruments, Huntingdon, UK) was used to produce sinusoidal driving signals of the desired duration and frequency, which were then amplified using a WMA-300 high-voltage amplifier (Falco Systems BV, Katwijk aan Zee, The Netherlands) up to 300 V peak to peak, combined with a 200 V dc bias voltage from a ESO300-0.45 power supply (Delta Elektronika BV, ZierikZee, The Netherlands), and then sent to a Senscomp 600 series capacitive ultrasonic transmitter (Senscomp, Livonia, Michigan, USA). The Senscomp transducers have a design center frequency of 50 kHz but previous work has shown that these devices can operate at frequencies between 10 kHz and 250 kHz with an estimated output level of 64 dB and 89 dB, respectively, at a distance of 0.5 m [13].

An apparatus was constructed so that four Senscomp 600 transducers could be used simultaneously, so that a selection of individual bees could be placed in four individual transparent enclosures to observe their behaviour during the application of the airborne ultrasound, as shown in Fig. 3. Forager bees without pollen were collected from the entrance of a single hive and used in the observation experiments. A small amount of honey was added to each enclosure to monitor any possible effect on feeding behaviour. As a control, an additional four transparent enclosures containing disconnected ultrasonic transducers were also used to eliminate the presence of the transducer as a possible confounding factor, but exposed the control bees to the same environmental conditions.

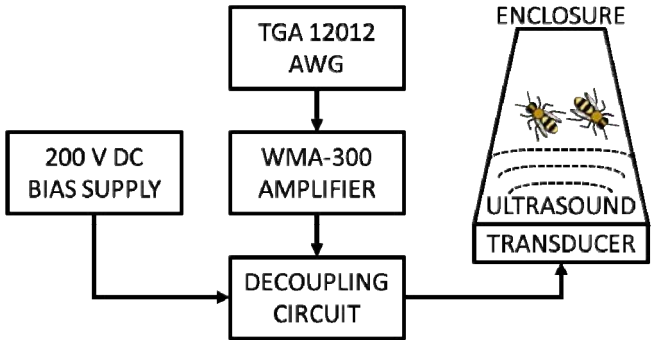


Fig. 2 Schematic of the initial ultrasound apparatus used for the bee behaviour observation experiments.

The behaviour observation tests were carried out as follows. After the individual bees were placed in their transparent enclosures, the ultrasonic system was switched on and the bees were exposed to high-intensity, high-frequency ultrasonic waves for 3 minutes, and then the system was switched off for 3 minutes. This on-off cycle was then repeated three times for a total duration of 18 minutes per test. Four control bees and four exposed bees were monitored using scan sample methods over the 18 minutes. Bee behaviour was classified as grooming, walking, standing still, flying, or feeding and the positions of the bees within the enclosures (base, side, or top) were noted.

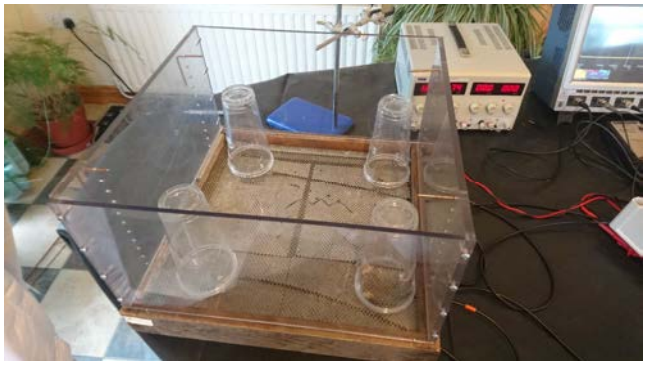


Fig. 3 Enclosures used for observation of bee behaviour during ultrasonic exposure.

B. To assess the efficacy of in-hive ultrasonic exposure

A second series of experiments was devised to determine if prolonged exposure to the airborne ultrasound could be used to treat entire hives using an in-hive system, by counting the number of *Varroa* mites dropped onto the base board of a hive before, during and after insonification. A customised ultrasonic driving circuit was developed to replace the benchtop equipment from Fig. 2 that was still capable of providing an identical high-voltage (up to 500 V) high-frequency driving signal along with a dc bias voltage for the Senscomp 600 transducers from a single low voltage

dc source, as shown schematically in Fig. 4. As part of these initial experiments, the circuit was used to power a number of Senscomp 600 transducers simultaneously, producing a number of sources of high-intensity high-frequency airborne ultrasonic waves inside the beehive.

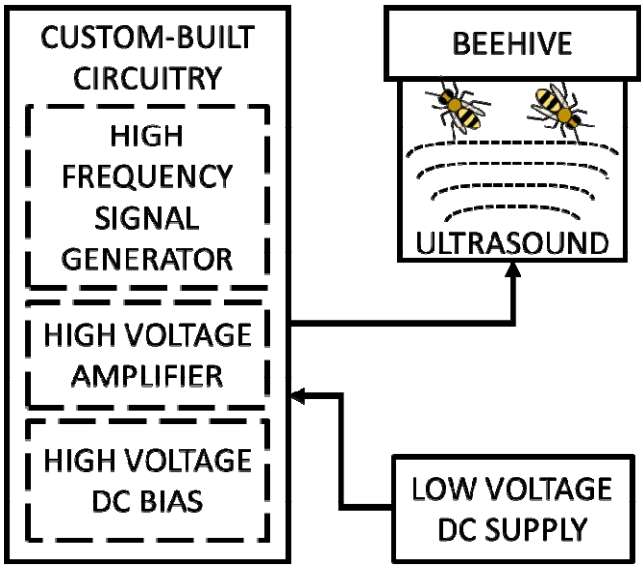


Fig. 4 Schematic of the custom-built in-hive ultrasonic system powered by a single low voltage dc power source.



Fig. 5 A typical national bee hive used for the in-hive tests, showing the white base board used for the mite drop count.

A selection of national beehives containing frames with a mixture of bees, brood and honey were sealed to prevent the bees from escaping and then brought indoors for ultrasonic testing. The white drop board under each hive, as seen in Fig. 5, was removed, cleaned and replaced after the hive was moved. The hive was then left to settle undisturbed for 30 minutes, after which time the board was removed and the mite drop count taken to establish a baseline count. The board was then cleaned and replaced before the ultrasonic system in the hive was turned on for a period of 30 minutes. After this time, the ultrasonic system was switched off and the second mite drop count on the board made after the period of insonification. The board was then cleaned and replaced under the hive for a further 30 minutes, after which time the board was removed for a third time and a final mite drop count made.

III. Results and Discussion

A. Bee behaviour observations

Four control bees and four exposed bees were monitored simultaneously using scan sample methods over the 18 minute experimental time. Bee behaviour and position within the enclosures were noted. The control bees were exposed to the same set-up and environmental conditions as the bees exposed to the ultrasound, only differing in that they were not physically exposed to any ultrasonic waves.

The results of individual bee behaviour in response to exposure to ultrasound are shown in Fig. 6 as a percentage of the number of observations, *n*. The average number of observations per bee over the 18 minutes of each test was 42 (± 6). Bees exposed to the ultrasound and the control bees were mostly observed to be walking, followed by feeding and grooming. There appeared to be no distinct differences in behaviour between the control bees or the bees exposed to the ultrasound. From these results it would appear that there is no immediate significant effect of the ultrasound on the individual bees.

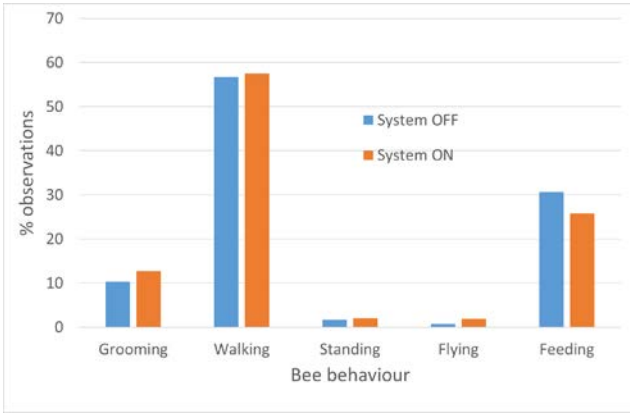


Fig. 6 Observation of bee behaviour with ultrasound system on (*n*=690) and off (*n*=662). Values are the percentage of the observations, *n*.

Bee position within the individual bee enclosures was also recorded simultaneously with the bee behaviour. Both the control bees and the exposed bees were observed mostly at the base of the enclosures. This may be due to this being the location of the small amount of honey placed in each enclosure for the bees to feed. The bees did not seem to be avoiding the part of the enclosure containing the ultrasonic transducers, even when the system was switched on.

B. In-hive ultrasonic exposure

Initial results using the system for full in-hive tests are shown in Fig. 7. There was an observable effect on the mite drop in two of the hives (Hive 1 and Hive 2), where the mite drop increased significantly during the period of insonification and continued at an elevated level after the system was switched off, compared to the initial baseline count. However, the other hives showed little effect. After testing it was discovered that Hive 5 had a new queen which

had not started laying eggs, so very few *Varroa* would have been expected in Hive 5.

One hypothesis is that the airborne ultrasonic waves stimulate auto-grooming and allo-grooming, in which the bees remove the mites from themselves and each other, respectively, within the hive.

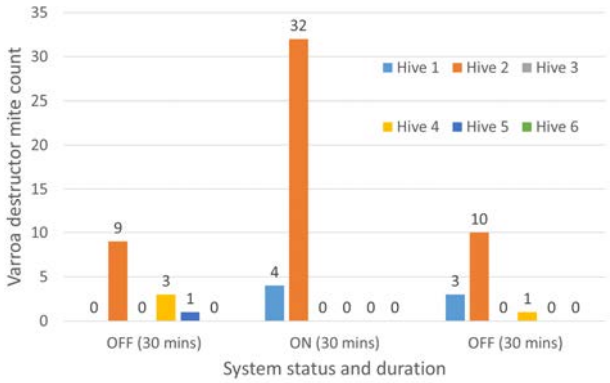


Fig. 7 Mite drop counts from initial in-hive testing in six beehives.

A number of other factors may have influenced the experiments. There is a large amount of variability in behavior between different colonies of bees; some are more aggressive, less active, or more hygienic than others. The mesh screen underneath each hive may sometimes be covered in propolis and other particulate matter dropped by the bees to a varying degree, as shown in Fig. 7. This may indicate the bees are more active, and more likely to allo-groom, or are trying to block the holes in the mesh for some unknown reason. The propolis layer may also influence the propagation of the ultrasound in the hive by reflecting the airborne waves, which merits further investigation.

IV. Conclusions and Future Work

A prototype system, for the possible control of infestations of *Varroa destructor* mites in beehives, was constructed that produced high-intensity high-frequency airborne ultrasonic waves. A series of experiments in which individual bees were exposed to the ultrasound showed no observable or immediate effect of the ultrasound on bee behaviour. A second series of experiments, in which the system produced airborne ultrasound inside national hives containing bees with *Varroa*, produced promising initial results that showed a dramatic increase in the mite drop rate in some of the hives tested. However, due to the inherent natural variability of bee behaviour and bee productivity between individual hives, additional testing is required. A series of field trials, using multiple hives containing ultrasonic systems and other co-located hives without systems to act as controls, is ongoing.

Acknowledgments

The authors would like to thank Mr Timothy Power and Mr Michael O'Shea for constructing the enclosures and for making modifications to the hives for the ultrasonic systems.



Fig. 8 An example of propolis covering the hive mesh. *Varroa* mites were also collected from the surface of the propolis layer.

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