Remote Hive Monitoring

Huw Evans Beng PH.d & Sandra Evans MSc

Introduction and Background to acoustic analysis

Most beekeepers can tell a lot about the condition of a honey bee colony the moment they remove the crown board. Therefore, the fact that such sounds have been documented since antiquity will come as no surprise. Virgil, ancient Rome's most celebrated poet and beekeeper, was the first to document a change of sound in a pre-swarming hive (Georgics, IV). A century later Columella, a Roman soldier and farmer, also noted: "He will be able to find out beforehand their decision to escape by putting his ear to each of the hives in the evening". (De re Rustica, 50 AD). Curiously, despite a seemingly deep understanding of bee behaviour, the ancient Romans also believed that bees could be obtained from dead cattle! In 1609 Charles Butler published his book *'Feminine Monarchie'*, in which he discusses both queen piping and change in noises preceding a swarm. Remarkably, he also writes a four part musical piece, titled *Bee-Madrigall*, intended to imitate queen piping and swarming bees. One hundred and fifty years later, in '*A Treatise on Management of the Bees*, Thomas Wildman also speaks of a peculiar humming noise in the hive three to four nights before "the swarm sallies forth" while noting that the interpretations of this sound vary from author to author "owing to the strength of imagination in each." The latter is a particularly astute observation, which remains relevant right through to the present day.

Possibly the best known pioneer of using acoustics as a diagnostic tool for bee husbandry is Edward Farrington Woods. A sound engineer by trade, Eddie used electronic apparatus to study bee acoustics for over a decade. He published his finding in both Nature (1959, Vol. 184) and the New Scientist (1963, Vol. 341). He produced a piece of apparatus called the Apidictor, this filtered out the sounds of interest.

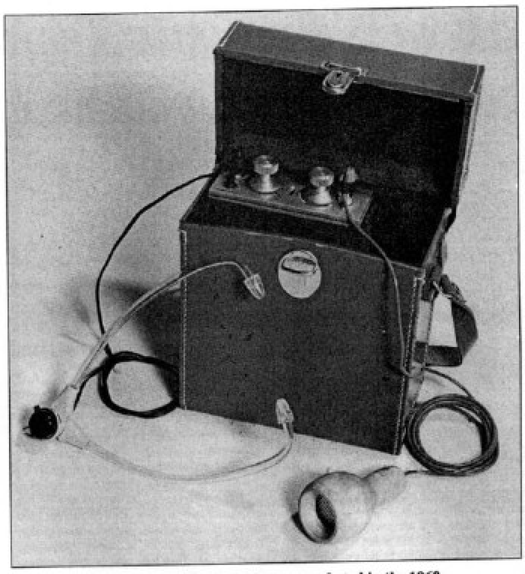


Figure 1: Image of the Apidictor, taken from Listen To The Bees, http://www.beedata.com/data2/listen/listenbees.htm)

Incorporating the technological advances of the day, Scandinavian beekeeper and engineer called O. Vancata went on to design an instrument he called "The Bee Tone Analyser" (Figure 2). The basic functionality remained the same as the Apidictor as did the operational drawbacks, namely that an evening trip to the hives was still required and a musical ear remained necessary. It is unclear whether more than one of these devices was ever made.

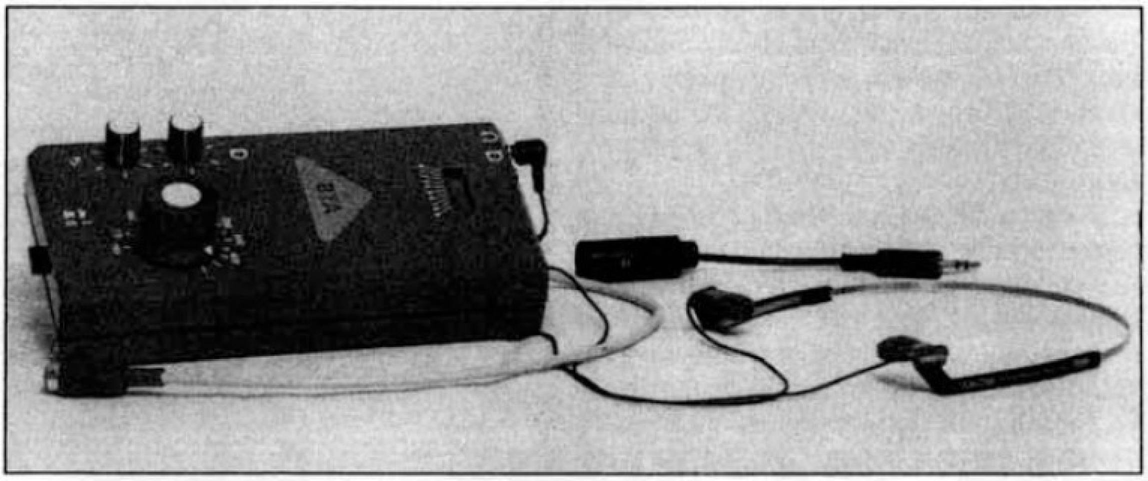


Figure 2: Image of Bee Tone Analyser (taken from the ABJ Sept 1995)

More recently, Bee Alert Technology from University of Montana have used bee acoustics to detect exposure to toxins, africanised bees, Varroa and other ailments. (Bromenshenk et al, 2009).

David Atauri (2009) from Spain has developed a platform of microphones and temperature sensors to monitor continuously conditions of the hive, with the aim to create a world wide database. A research group form Nottingham Trent University have used accelerometers in the hive walls to detect vibrations for swarm prediction (Bensick at al 2011). However, all of the above developments required sophisticated and cumbersome equipment (PCs etc) not suited to everyday use by a beekeeper in an apiary.

Having considered Wood's research in detail, and with the application of modern day technology, we set out to develop an affordable and portable hive monitoring system that would gather acoustic and other physical data from the hive and relay it to a central server. This would allow issues or problems to be reported via email or SMS and also allow users to login and remotely check the status of their hives

Materials and Methods

Initially, we started recording bee sounds while making frequent manual inspections. This allowed us to accurately correlate changes in sound with changes in colony behaviour.

Data collection

Two test sites were used each containing eight hives. One is in the UK monitoring the 'black' *(Apis mellifera mellifera*) bees, the other in Italy monitoring the 'yellow' (*Apis mellifera ligustica*) bees. Sound data from the hives is collected via a separate microphone for each hive. These microphones are fed into an 8 input sound card which connects to a standard desktop PC using a fire wire connection. The microphone is an Audio Technica ES 945 boundary microphone. This is a high quality condenser microphone designed to be screwed into ceiling tiles or table tops making it ideal for mounting. Furthermore it is very sensitive and has a particularly flat frequency response around our frequencies of interest. The 8 channel sound card provides both pre amplification and phantom power at the microphone inputs.

Data Analysis

The audio data from the hives has been continuously recorded at a sampling frequency of 44100 Kb/s and saved in .wav format all one hour in duration. For data analysis these files have to be split into smaller more usable sized chunks. Due to the relatively large variation in and stochastic nature of the noise within a hive, from moment to moment, the size of the split files fed to the frequency analysis software must be large enough to allow the analysis software to take a reasonable average. However, the files must also be short enough to allow sufficient resolution across the time frame being considered and small enough as not to choke the analysis software. The frequency spectra of each audio file can then be obtained using a Fast Fourier Transform (FFT). These results are stored and the process repeated for the next file. Once frequency spectra have been generated for all files over the period being studied, they can be plotted over time on a 3D graph or 'Soundscape'. This allows us to observe trends in sounds (such as the warble) over hours, days or months. For the file splitting we purchased a program called Gold Wave. It is both highly versatile (allowing noise reduction and batch file splitting) and inexpensive. We developed an analysis program using Octave (a Matlab compatible program that is freeware). This enabled the development of a program we could feed files, perform and average the FFT, store and plot the results on a 3D graph.

Soundscapes

Swarming

We used our analysis program to graph the sounds from inside two neighbouring hives. As the timescale of the analysis was relatively large (over several weeks) the .wav files were split into 15 min chunks which we found to be verging on the maxim size that Octave could reliably consume. We graphed the frequency spectra recorded at midnight within these two hives over a three week period prior to one of them swarming. Each graph has 42 points (two per night) which took approximately half and hour to compute. Not only were the hives geographically close (standing next to each other) but they were also of similar size, activity and the queens were of comparable vitality.

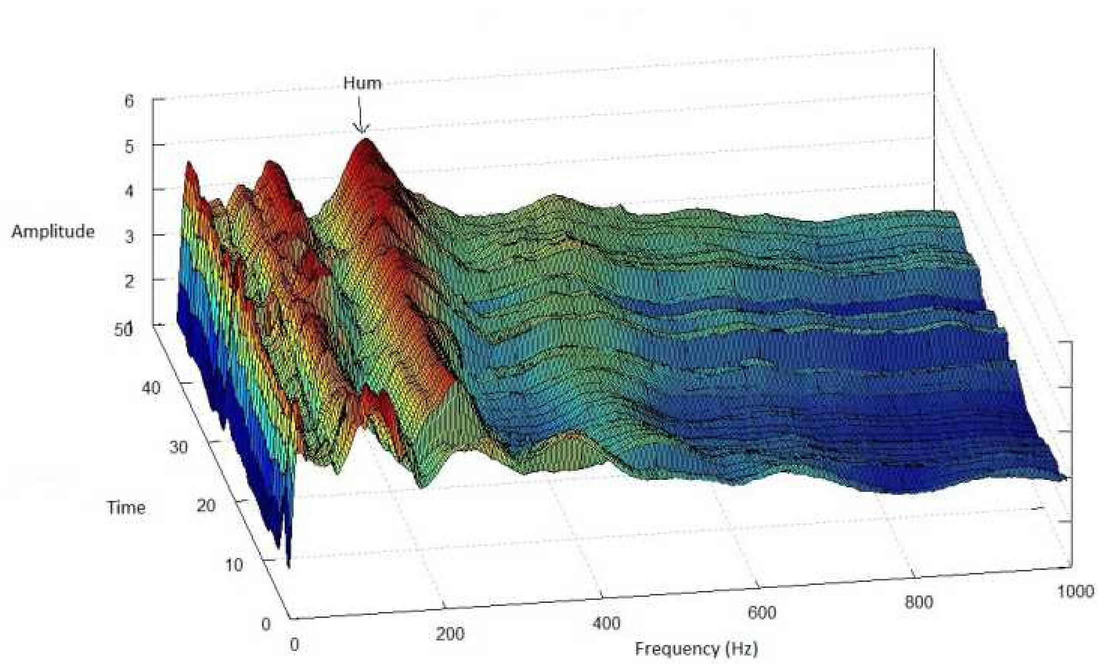


Figure 3: Three week soundscape from a colony that did not swarm.

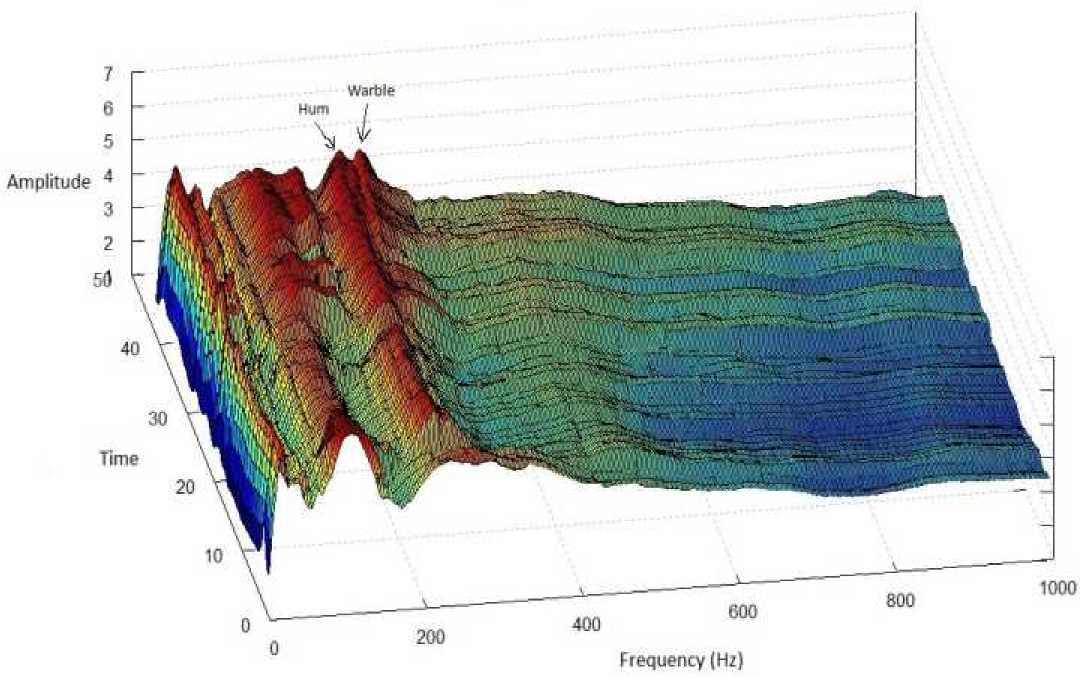


Figure 4: Three week soundscape from a colony that did swarm.

As you can see from the graphs, the second hive is clearly demonstrating a warble. This hive swarmed. Repeating the process on the other data we collected it became apparent that the sound signature is not always as obvious as it appeared in the examples above. The amount of warble varied between swarming hives, a colony that swarmed and then continued to cast did not produce the same disturbance in the warble frequency range. Furthermore, colonies superseding their queen also created a disturbance in the warble range. To date we have recorded 25 TB of acoustic bee data.

Hardware realisation

The remote hive monitoring system configuration can be seen in the figure below:

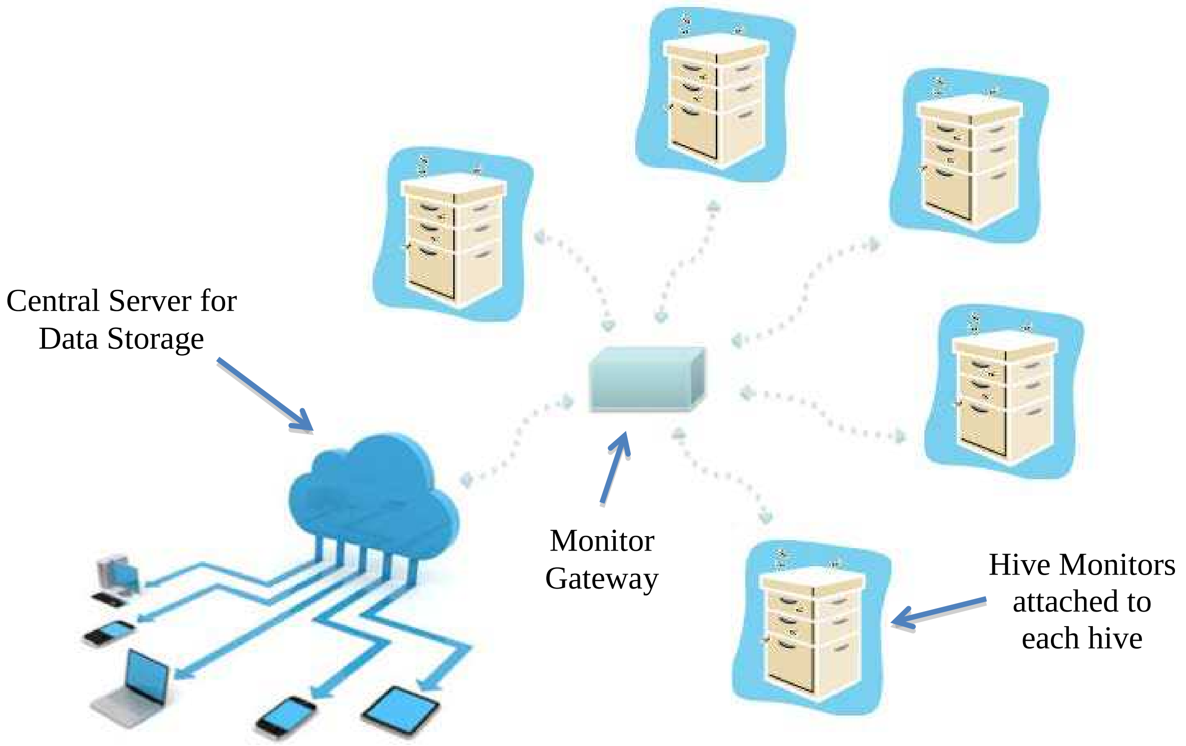
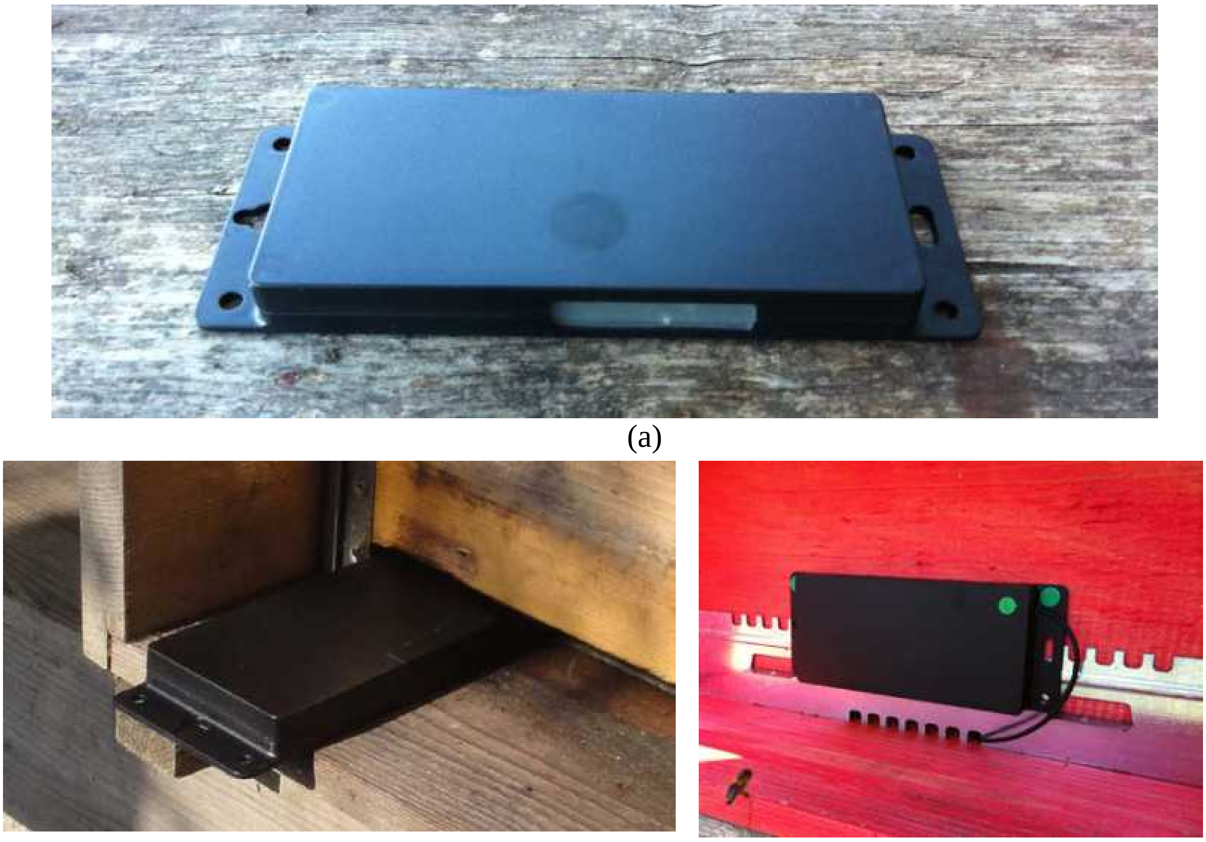


Figure 5: Monitor configuration

The individual Hive Monitors (as seen in Figure 6a) are only 15mm thick so can be placed either inside the hive below the brood frames, mounted to a dummy board fixed to the front of the hive above the entrance (as seen in Figure 6b). They are powered by 4 x AAA batteries and have a low power Xbee radio module which allows them to communicate measurements back to a battery powered Master unit or 'Monitor Gateway' which is placed centrally in the apiary. The Monitor Gateway (Figure 7) collects the data from all the hive monitors and communicates this data back to a central server using the 2G GPRS network where it can be accessed via any internet enabled device. For areas of no mobile coverage, the Monitor Gateway is capable of storing 2200 readings onboard. This data can be extracted using a standard laptop and USB lead.



(a)

(b) (c)

Figure 6: (a) Hive Monitor; (b) Hive Monitor being put inside the hive; (c) placed above the hive entrance

The hive monitors are fitted with the following sensors as standard: condenser microphone, an on board accelerometer to measure vibrations and also used for theft detection, an internal temperature sensor, an external temperature sensor on a flying lead to measure hive or brood temperature, external humidity sensor on a flying lead to measure hive humidity. The hive monitor can also interface to an external accelerometer (including 24V power supply), as well as having an additional ADC input for other external sensors. A relay input is also available to interface with traditional bee counters.

The Monitor Gateway also has an internal temperature sensor used to record ambient air temperature at the apiary.

Accessories

The Monitor Gateway can be equipped with a weather pack and external antenna for areas for weak mobile coverage (Figure 7). The weather pack, which includes both a self emptying rain gauge and sunshine sensors, enhances the monitoring capability of apiary weather conditions.

Figure 7: External Antenna and Weather Pack

Hive Scales are also available so the weight of the hive can also be monitored (Figure 8). The scales have a unique 'open floor' design to allow debris to drop from open mesh floors and increase hive ventilation. Being 3.5cm high they are low profile thus not requiring adjustments to the existing hive stand height. Using multiple load cells the scales are ideal for uneven loads removing the 'skew' problem associated with single load cell designs. The maximum load is 150 kg with a resolution of 10 g, the scales are fully wireless and can simply be added to the system at any point in time.

Figure 8: Arnia Hive Scales

User interface

The data collected by the monitors is sent to the central server and it can be accessed on any internet enabled device by the users logging into a previously created account, as seen in figure 9 below.

Figure 9: Web based user interface: Hive View and Instant Alert

From the ‘Hive View’, at a glance the user can assess the state of their colony. The readings from sensors are displayed in the appropriate icon on any given hive. Below each hive, the signal strength and battery level of each Hive Monitor is displayed. The cluster of bees above each hive reflects that hive’s activity or strength. The weather bar shows current and historical weather conditions along with the signal strength and battery condition of the Monitor Gateway.

The user can access historical readings from any of the sensors by simply touching or clicking any of the sensor icons (such as temperature, activity, weight and humidity). This opens the relevant graph for that sensor (Figures 10 and 11).

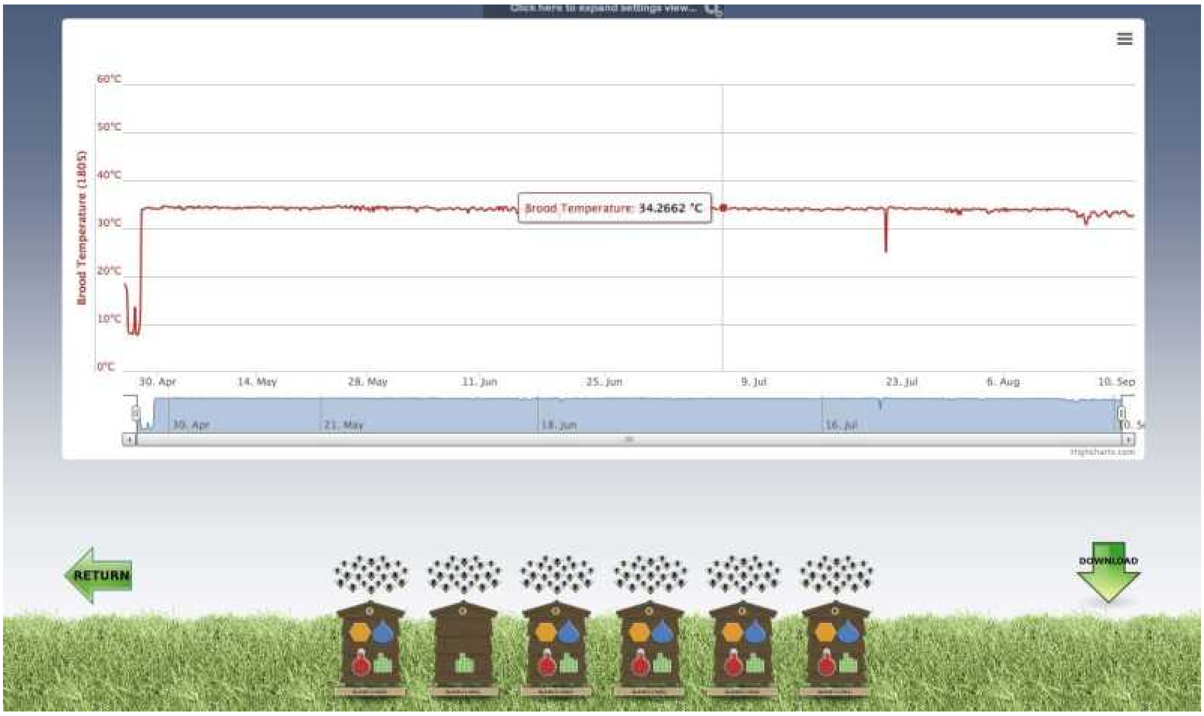


Figure 10: Brood temperature

Another sensor from the same hive can easily be added to the graph by clicking on the relevant icon as seen in figure 9.

Figure 11: Brood and hive temperature comparison

In the same way, sensor reading from other hives can easily be included on the same graph for comparison. A slider bar along the bottom of the graph allows you to zoom in on any part of the data that is of interest.

The user can also set up a system of alerts to via email or SMS. These alerts include low battery, theft and various sensor thresholds.

Discussion and Conclusion

Although the swarming soundscapes were not conclusive, throughout the course of the experiment we observed other interesting trends in the sound signatures such as health status which we are currently in the process of investigating these further. Nonetheless, the ambiguity of a soundscape can be reduced by considering other parameters. For example, an unstable brood temperature can indicate a queen that is not laying. Furthermore, a drop in foraging activity is often observed prior to swarming. Coupled with the time of the year, this combination of information can be a very useful aid to swarm prediction.

Having access to the weather conditions at the apiary, both current and historical, can also be very useful. Beekeepers with out apiaries, particularly in mountainous areas where weather can differ significantly over small distances, can check the weather is suitable for hive inspections before setting off.

Unstable brood temperature can also indicate that the colony is queenless. Similarly, stabilisation of brood temperature can be a very reliable indication that the queen has mated and started laying. This is potentially very useful information for a queen breeder. If it is known when a queen starts laying it is possible to estimate the time of mating, which in turn can be triangulated with the historical weather data. If the weather was poor around the time of the mating flight the chances are the mating was not optimal, in which case the beekeeper can take appropriate action such as raising more queens.

The benefits of having the weight data include being able to accurately map the nectar flow, knowing when to add or remove supers as well as winter monitoring for the amount of stores that is available to the bees. Flight noise can show how much the bees are flying, but together with weight data they can show how efficient the foraging has been.

The system of instant alerts for security is a simple yet very effective one, where an alarm message can be sent to the beekeeper should his hives be moved or tipped over. Things like broodless state can also trigger off an instant alert if desired. Similarly, users can set thresholds for various sensor measurements (high or low temperatures, humidity etc.) and when these are reached an alert is issued to the user.

The detail of the data collected and the ease with which it is accessed makes the monitors a valuable research tool. In these rather uncertain times for the bees there is a lot effort concentrated on researching the maladies of the bees and the monitors offer a possibility to log all the vital statistics of the hive such as colony strength, activity, build up rate, as well as allowing for the mapping of nectar flow. The system can be used on many hives in the same apiary or across different geographical locations for comparative purposes, i.e. helping to spot trends across wide geographical areas. We are currently working on a general knowledge base to interlink with the data so that practical advice can be offered when required.

In a world where the electronics have a virtually indispensible role an appearance of electronic beekeeping gadgets was to be expected. The ultimate use of information collected by such a system and how it can help beekeepers will evolve with use over time. Arnia's monitor is not however conceived to replace the beekeeper or to breed lazy beekeepers, on the contrary, it is intended as a tool which can help beginner beekeepers to gain better understanding of honey bee management. To an experienced beekeeper it can help minimise the unnecessary disruption to the colonies that do not require intervention and therefore allow more time for activities such as pest management and equipment maintenance.

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