QUANTITATING THE LOCAL HONEYBEE HIVE FRAME LOAD USING VIBRATIONAL MODES

BAJARE S[1], BENCSIK M[1], MCVEIGH A[2], CAPELA N[3], LUMSDON M
[1]NOTTINGHAM TRENT UNIVERSITY, UK, [2]HARRY BUTLER INSTITUTE, MURDOCH UNIVERSITY, AUSTRALIA, [3]CENTRE FOR FUNCTIONAL ECOLOGY, DEPARTMENT OF LIFE SCIENCES, ASSOCIATED LABORATORY TERRA, UNIVERSITY OF COIMBRA, PORTUGAL

Introduction

Honeybee activity is responsible for pollinating 75% of the crops that are consumed worldwide [1]. Throughout the years, due to pesticides, parasites, diseases, and climate change there has been a decline in the population of honeybees [2,3]. To protect the honeybees from these, constant manual inspection accompanied by timely and adequate intervention by the beekeeper is the key to colony's survival. However, this is invasive, requires intense labour and expertise. Automatic beehive monitoring is a new technique that uses sensors to measure the hive environment. The data collected continuously through these sensors such as temperature, humidity, and weight are analysed remotely, providing beekeepers with valuable insights into the health and productivity of their hives without opening their hives.

- Our approach is to use multiple accelerometers on different positions of the frame, to measure vibrational amplitude as a function of frequency with a view of tracking the frame contents. Here we have been extracting, quantitating and calibrating the frame load by loading gelatine capsules individually filled with sand or flour inside the honeycomb one at a time.

Methods and Materials

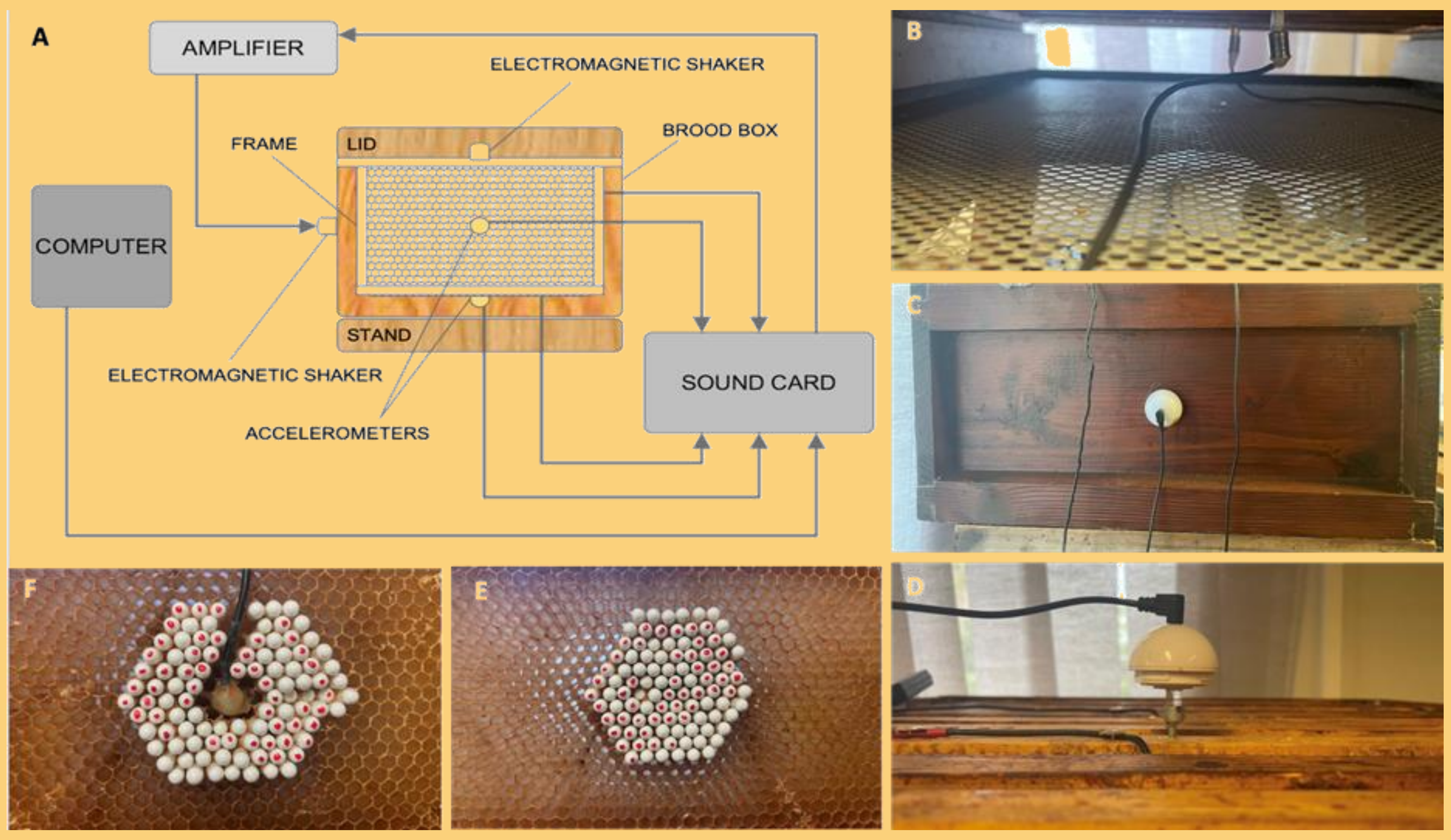

Figure 1 | Experimental setup. The diagram in panel (A) shows the overall layout of the experiment, with the electromagnetic shaker mounted on the side of the brood box (C) and on top of the loaded frame (D). There are 4 accelerometers placed at two different positions: 2 accelerometers inside the honeycomb of control frame and loaded frame (F) and 2 accelerometers at the bottom of these frames (B). The loaded frame is gradually loaded and unloaded with 100 flour filled capsules on each side of the honeycomb, shown in panel (E) and (F).

- We have performed 8 different experiments where we have used two different types of frames: (i) brood box frame, which is referred as deep frame and (ii) super frame, which is referred as shallow frame. The contents of the frames are artificially changed by loading gelatine capsules (Agar Scientific, Size 4) of different mass density: flour filled capsules (0.211$\pm$ 2g) (figure 1.e,f) and sand filled capsules (0.37 $\pm$ 2g).
- There are four accelerometers (805M1-0020, TE Connectivity Measurement Specialties) used (figure 1.b,f). This was the preferred choice of accelerometer because it has been shown [4] that the quality of the signal of this accelerometer is at par to Brüel & Kjær (4507), an expensive and ultra high performing accelerometer.
- Two accelerometers are inserted inside the wax by melting the wax on top of the accelerometer (figure 1.f). The other two are mounted on the wood, at the bottom of the frame (figure 1.b). These will extract the vibrational data from the acceleration on the wax and wood, respectively and give insights on how different mounting can affect the accelerometers readings.
- An electromagnetic shaker (Mighty boom ball, E.U. Xtores) is mounted (i) on the side of the brood box (figure 1.c) and (ii) on the top of the control frame (figure 1.d), to investigate the optimum mounting position of the transmitter.
- The vibration waveforms driven from the electromagnetic shaker are supplied from a computer through the sound card. These vibrations are enhanced by an amplifier before reaching the electromagnetic shaker, as shown in figure 1.a.

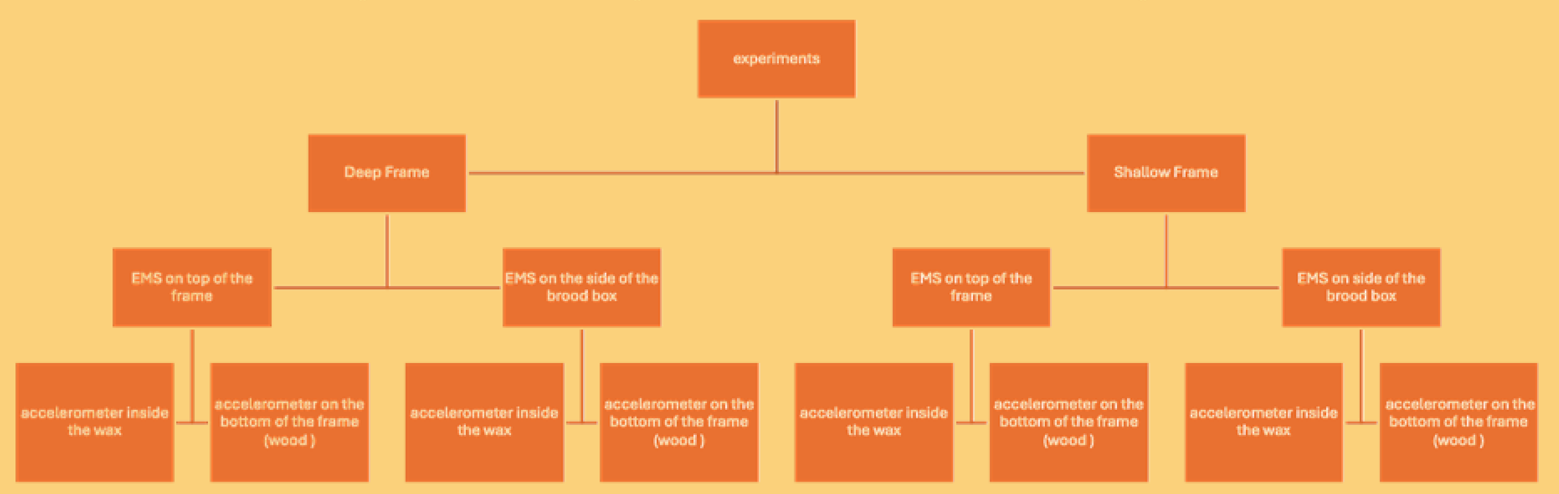

Figure 2 | Experimental Hierarchy Diagram for quantitating the frame load. The hierarchy diagram shows all 8 experiments performed, with the (i) type of frame used, (ii) location of electromagnetic shaker (EMS) and (iii) placement of the accelerometers.

- We repeated these 8 different experiments (figure 2) 3 times (24 total experiments) to check the repeatability of the results. An example of an experiment is: both the control and loaded frames are deep frame, with electromagnetic shaker (EMS) mounted on top of the frame and the accelerometers are placed inside the wax and on the wood, at the bottom on both control and loaded frame.
- One frequency sweep takes 60 seconds. An experiment, including loading of flour/ sand capsules one at a time, until there are 100 capsules on each side of the frame, followed by unloading the capsules in similar manner takes around 90 minutes.
- Honeycombs that are less than 6 months old are sensitive to change in temperature [5]. To avoid significant change in the results, we performed the in around 90 minutes.
- All measurements are stacked from top to bottom and shown in figure 3, where the dark red color signifies a high vibrational amplitude and light blue color signifies a low vibrational amplitude.
- Principal component analysis (PCA) is used to reduce the dimensionality of the dataset to efficiently analyze the data and to keep the information loss to a minimum. The first principal component accounts for the most variance in the data, the second principal component accounts for the second most variance in the data, and so on. PCA scores are the values of the principal components for each data point. From the data matrix, PCA scores and Eigen vectors are calculated in Octave.

Results

- The resulting spectra of one experiment and its Eigenspectra are shown in Figure 3.

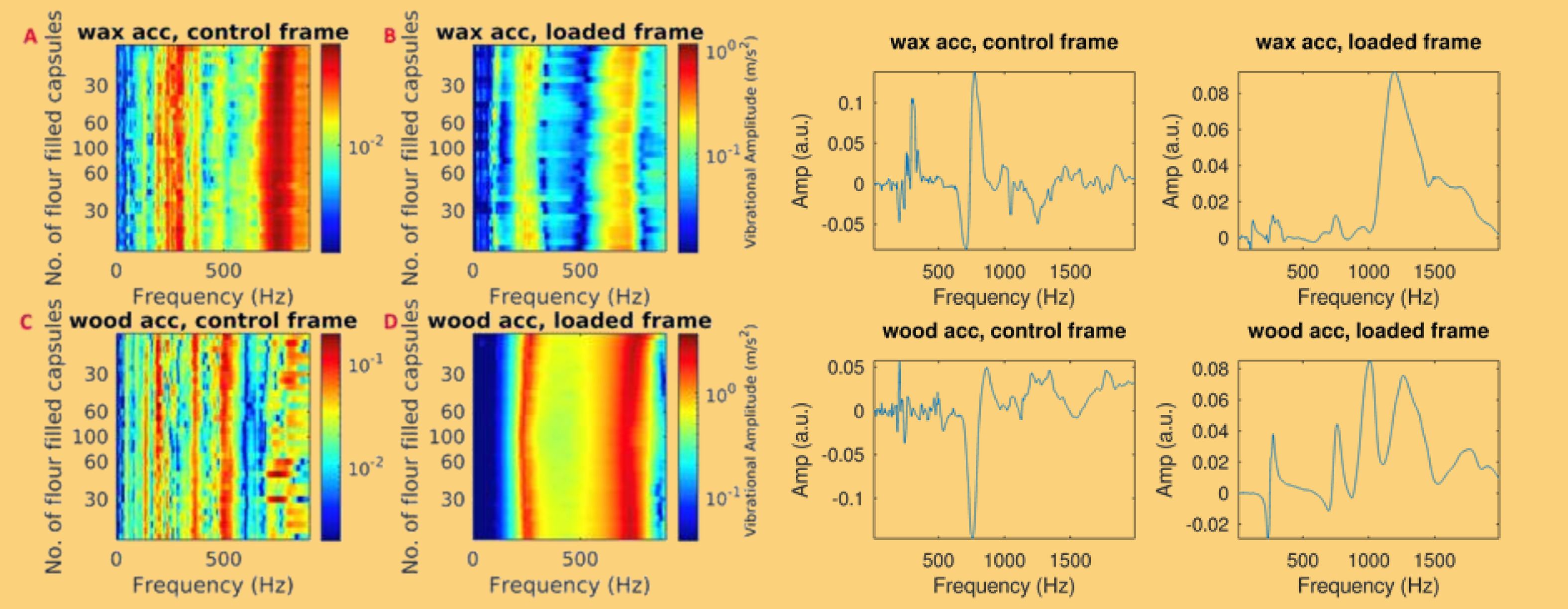

Figure 3 | Vibrational Spectra (left) & Eigenspectra (right). The left illustrates a series of vibrational spectra for the data collected on a deep frame, when the vibrations are driven on top of the loaded frame, showing the amplitude and spectral peak frequency change when the frame is gradually loaded, then unloaded (B, D) with flour filled gelatine capsules. These changes are negligible in the control frame (A, C). The loaded frame results (B, D) also show the reversibility of the amplitude and spectral peak changes when loading (0-100) and unloading (100-0) of capsules in the frame. The color coding represents logarithmic vibrational amplitude from low (Blue) to high (red) in m/s^2. The Right, shows the eigenspectra of the same experiment, illustrating the most significant deviations in a spectra by identifying the changes in the vibrational spectra over time.

- The PCA Score and sensitivity of control and loaded deep frames (when the vibration is driven on top of the loaded frame through electromagnetic shaker with 2 accelerometers embedded inside the wax and 2 accelerometers mounted on the bottom of the frame, on the wood) is shown in figure 4.

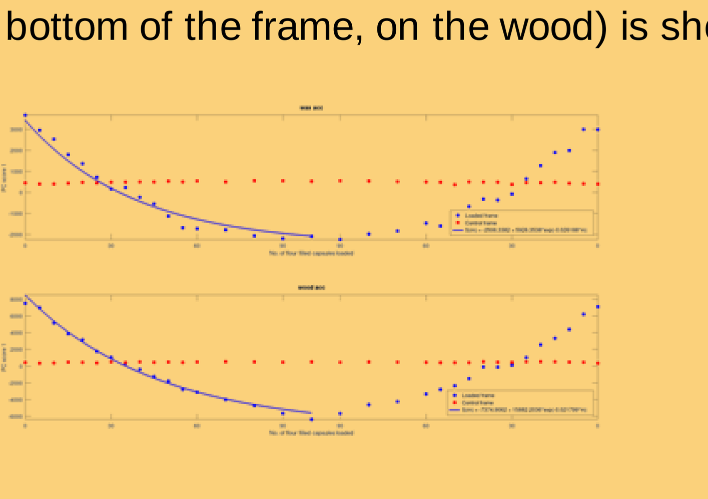

Figure 4 | PCA scores and sensitivity for wax and wood acceleration on both control and loaded frame. The blue dots represents the PCA score of the loaded frame. An exponential decay is fitted on these dots, representing the sensitivity of the experiment. The red dots are First PCA score calculated by cross correlation of first eigen spectrum of the loaded frame and the spectrum of the control frame. It can be observed that (i) there is negligible change in the control frame (ii) there is reversibility of the experiment (loading - unloading of capsules). (iii) wood acceleration is more sensitive than wax acceleration.

The results shown here are one of three separate experiments undertaken under identical conditions to assess repeatability.

Discussion

- Our method used in very sensitive to the change in the contents of the frame load, thus giving an accurate and reliable result.
- The control frame shows negligible variance to the change in amplitude.
- The experiment is repeatable and reversible.
- This developed method is minimally invasive and inexpensive.
- We have extracted a meaningful and useful scalar from a complex data, using PCA.
- Knowing the mass density of the frame might allow the assessment of the contents of the frame, for example: (i) honey, (ii) pollen, (iii) brood.
- Knowing the amount of honey remaining in the colony, the beekeeper knows when to feed the hives in winter.
- Exploiting the high specificity of the Fast Fourier Transform to a sinusoidal wave, our method is remarkably resilient to any external noise, including vibrations coming from the honeybees (work not shown), making the collected data highly accurate even in challenging environments.

Conclusion

- An automatic beehive monitoring system that is minimally invasive and provides promising economy of (i) inspection efforts (ii) winter food supply.
- By our method, the beekeeper will know the mass density load of his frames without opening the hives.
- Further work focuses on: (i) Performing the experiment on a natural frame with honey, pollen and brood. (ii) using multiple accelerometers inside the wax to increase the accuracy of the system.

References: [1] Kewanit Alemberhe and Kidu Gebremeskel, 'A Review on: Role of Honey Bee Pollination in Improving Crop Productivity and Seed Quality in the Northern Ethiopia', 2016. [2] Renée Johnson, Honey Bee Colony Collapse Disorder (Washington D.C.: Congressional Research Service, 2010). [3] José M. Flores et al., 'Effect of the Climate Change on Honey Bee Colonies in a Temperate Mediterranean Zone Assessed through Remote Hive Weight Monitoring System in Conjunction with Exhaustive Colonies Assessment', Science of The Total Environment 653 (25 February 2019): 1111–19, https://doi.org/10.1016/j.scitotenv.2018.11.004. [4] Martin Bencsik and Michael I. Newton, 'Honey Bee Vibration Monitoring Using the 805M1 Accelerometer', Proceedings 4, no. 1 (2018): 42, https://doi.org/10.3390/ecsa-5-05637 [5] Kai Zhang et al., 'Hierarchical, Multilayered Cell Walls Reinforced by Recycled Silk Cocoons Enhance the Structural Integrity of Honeybee Combs', Proceedings of the National Academy of Sciences 107, no. 21 (25 May 2010): 9502–6, https://doi.org/10.1073/pnas.0912066107.

NOTTINGHAM TRENT UNIVERSITY

Murdoch University

Harry Butler Institute

UNIVERSIDADE D COIMBRA

CENTRE FOR FUNCTIONAL ECOLOGY