QUEEN HONEY BEE DETECTION USING SOUND FREQUENCY ANALYSIS

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Introduction:

Apiculture, also known as beekeeping, plays a crucial role in agriculture and biodiversity through pollination and honey production. Effective management of bee colonies is essential for maintaining hive productivity and health. One of the critical factors in hive stability is the presence of a queen bee, whose absence can lead to colony stress, reduced productivity, and potential collapse. Traditional methods of monitoring queen bee presence are manual, time-consuming, and often unreliable.

This project aims to develop a smart hive monitoring system capable of detecting the presence or absence of a queen bee using audio signal processing. Honey bees communicate through various acoustic signals, and changes in these signals can indicate the queen's status. By capturing hive audio using microphones and analysing the frequency patterns, specific sound signatures related to queen presence or absence can be identified.

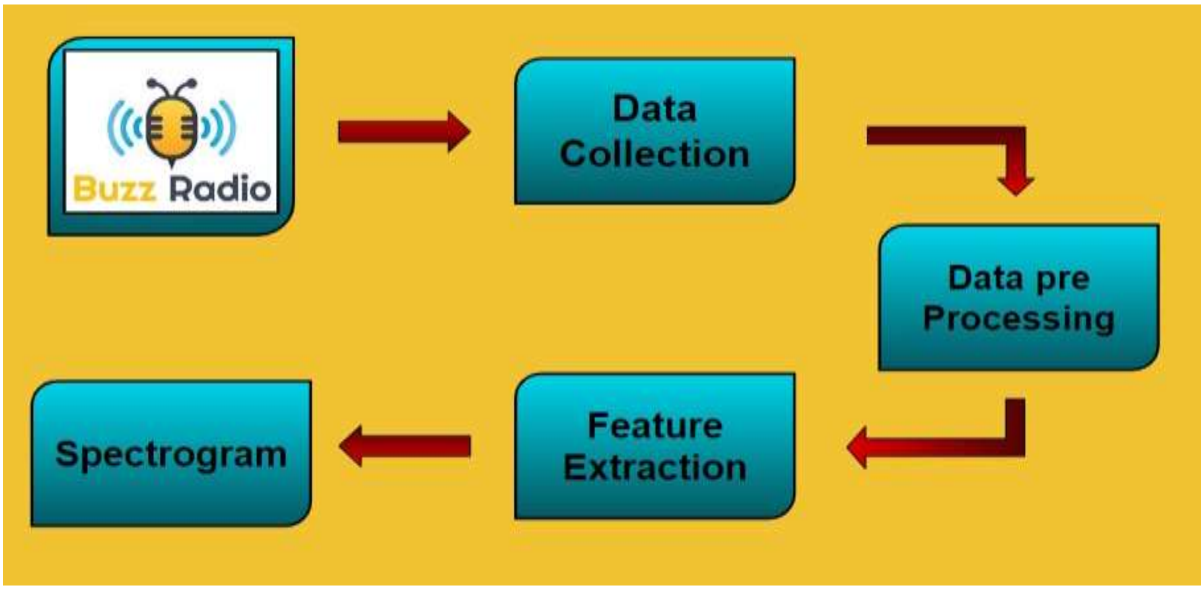
The collected audio data undergoes pre-processing, feature extraction, and classification using machine learning algorithms trained to recognize patterns associated with different hive states. The system provides real-time feedback to beekeepers, enabling timely interventions and improved colony management. This approach offers a non-invasive, scalable, and cost-effective solution for precision apiculture.

Objectives:

- To develop an intelligent system for real-time monitoring of beehive conditions
- To detect the presence or absence of the queen bee using acoustic signals
- To reduce manual inspection efforts through automation
- To support beekeepers with early warning alerts for hive disturbances
- To promote precision beekeeping using modern technological solutions
- To collect and analyse audio data from active beehives using microphones

Methodology:

The project begins with the selection of a healthy beehive for audio monitoring. Sensitive microphones are embedded inside the hive to continuously capture the natural buzzing and acoustic patterns produced by the bees. These microphones are connected to a raspberry-pi or data acquisition system capable of recording and storing audio signals. The recorded audio is then passed through a pre-processing stage, where unwanted background noise is filtered out using basic signal filtering techniques. The audio is segmented into smaller time windows to observe detailed patterns in the hive’s sound environment. The presence or absence of the queen bee affects the behaviour and communication of worker bees, which reflects in the hive’s acoustic signature. By analysing these sound patterns, variations in the hive's condition are observed and documented. These differences help in identifying changes related to queen presence. To support the result analysis, Mel-Frequency Cepstral Coefficients (MFCC) are extracted from the audio signals. The MFCC spectrogram provides a compact representation of the audio signal, focusing on the perceptually relevant frequency components.



This spectrogram is used to visualize and analyse how the frequency content of the hive's sound changes under different conditions. Experimental results based on MFCC spectrograms help in comparing normal and abnormal acoustic behaviour, offering insights into the effect of the queen bee's presence on the overall hive environment. This method enhances the understanding of bee communication and supports the development of an effective hive monitoring system.

Result and Conclusion:

The proposed system was successfully implemented using embedded microphones strategically placed inside the beehive to continuously monitor audio signals in real-time. These microphones captured the natural buzzing and communication sounds produced by the honeybee colony throughout various times of the day and under changing environmental conditions. The audio signals were subjected to pre-processing steps, including noise reduction and segmentation, to isolate meaningful sound patterns.

Following pre-processing, the signals were analysed using Mel-Frequency Cepstral Coefficients (MFCC) spectrograms. The MFCC analysis allowed for the extraction of frequency-based features that are closely aligned with how bees communicate. Visual interpretation of the spectrograms revealed distinct differences between the audio patterns of a healthy hive with a queen and a hive lacking a queen.

In the presence of the queen bee, the hive audio displayed a consistent and stable buzzing pattern, reflecting a calm and coordinated colony behaviour. Conversely, in the absence of the queen, the audio signals exhibited irregular, erratic, and disorganized buzzing. This change in acoustic behaviour clearly indicated stress or disorder within the hive. Several tests were conducted on different days, at varying times, and under diverse environmental conditions to ensure the system's reliability and repeatability. The consistency of results confirmed that MFCC spectrograms serve as a dependable tool for acoustic analysis in beehives.

This project successfully demonstrates a non-invasive, affordable, and efficient solution for continuous hive monitoring. It significantly reduces the need for manual inspections, which can be disruptive to bees. The system provides valuable insights into hive health and behaviour, especially regarding the queen's presence. The results support the potential of this method to be used as a foundation for further innovations in smart apiculture. With additional development and real-time integration features, it can serve as an advanced tool for promoting sustainable and data-driven beekeeping practices

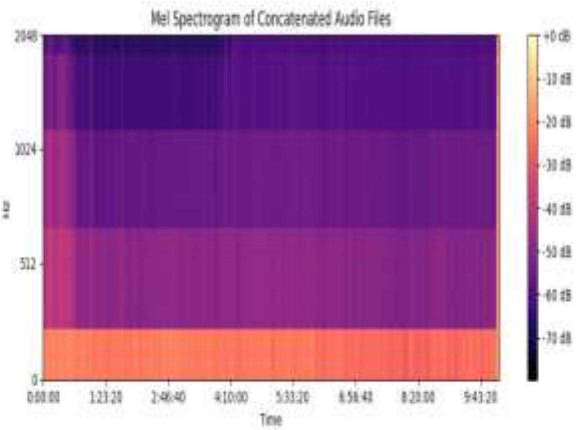


Fig.1 MFCC spectrogram of presence of queen beehive

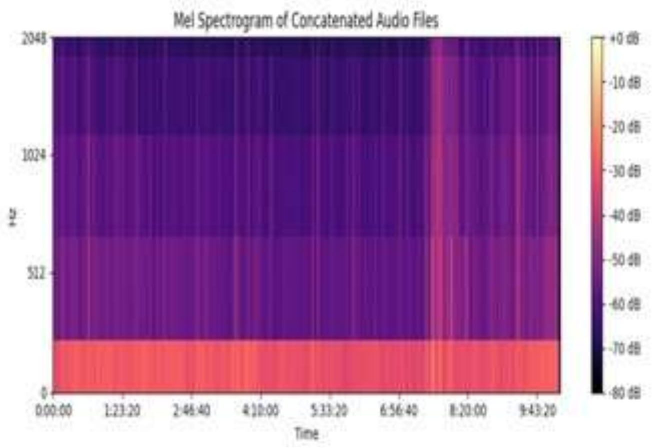


Fig.2 MFCC spectrogram of presence of queen-less beehive

Project Outcome & Industry Relevance:

The project successfully demonstrated a practical approach to monitoring hive health through acoustic sensing, focusing on detecting the queen bee's presence. It showed that using microphones and MFCC-based analysis can provide reliable, non-invasive insights into beehive behaviour. The outcome reduces the need for frequent manual inspections, which often disturb the colony.

This solution holds strong industry relevance, especially in commercial apiculture, where managing multiple hives efficiently is critical. By adopting such systems, beekeepers can detect early signs of hive stress or queen loss, preventing colony collapse and improving honey production. It also aligns with the growing demand for precision agriculture and smart farming technologies.

In the broader context, this project contributes to the field of agricultural automation and environmental monitoring. With further development, it can be integrated into IoT platforms and used by industries involved in pollination services, agricultural research, and sustainable farming practices.

Working Model vs. Simulation/Study:

This project involved the development of a **physical working model** rather than a simulation or purely theoretical study. The system was implemented using microphones and hardware components, which were installed inside an actual beehive for real-time data collection.

Audio signals from the hive were recorded, pre-processed, and analysed using MFCC spectrograms. The setup was physically tested under real beekeeping conditions, and the results showed clear differences in acoustic patterns between queen-present and queen-absent scenarios.

The successful real-world testing of the model validates its practical application and confirms the feasibility of deploying such systems in real apiculture environments.

Project Outcomes and Learnings:

The key outcome of the project was the successful development and testing of a real-time beehive monitoring system using microphones and audio signal analysis. The system effectively identified the presence or absence of the queen bee by analysing variations in hive sound patterns using MFCC spectrograms.

This project demonstrated the feasibility of using acoustic sensing for non-invasive hive monitoring, offering a cost-effective and practical solution for beekeepers. It also highlighted the potential of applying signal processing techniques in agricultural applications.

Through the process, we gained hands-on experience in hardware integration, audio data acquisition, and real-time environmental testing. We learned the importance of noise filtering, data pre-processing, and the challenges involved in working with live biological systems. Additionally, the project helped us understand the practical aspects of translating a technical idea into a working model and interpreting real-world results

Future Scope:

The future scope of this project includes:

1. **Integration of wireless data transmission** for remote hive monitoring without physical inspection.
2. **Development of a mobile application** to provide real-time updates on hive health and queen presence.

3. **Incorporation of environmental sensors** (like temperature, humidity, CO_2) to analyse complete hive conditions.
4. **Solar-powered hardware integration** for energy-efficient, long-term outdoor deployment.
5. **Improvement in sound analysis** using advanced DSP techniques for more accurate detection.
6. **Implementation of automatic data logging** to record hive data over time for trend analysis.
7. **Cloud storage support** for remote access to audio data and analysis results from any location.
8. **Detection of other hive events** such as swarming behaviour, colony collapse disorder, and pest invasions.
9. **Multi-hive monitoring system** to manage and track multiple colonies from a single dashboard.
10. **Integration with GPS modules** to track and manage mobile hives used in pollination services.
11. **Design of a user-friendly web dashboard** for beekeepers to visualize hive data trends and alerts.
12. **Automated notification system** via SMS/email to alert beekeepers about abnormal hive conditions.
13. **Expansion of frequency analysis database** with more hive samples for better accuracy across regions.
14. **Miniaturization of the hardware setup** to make it more compact and easier to install inside hives.
15. **Collaboration with agricultural departments** and local beekeepers for wide-scale deployment and testing.