

REAL-TIME VARROA MITE DETECTION IN HONEYBEES USING LIGHTWEIGHT IMAGE CLASSIFICATION MODELS ON EDGE DEVICES

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doi:10.34107/UDUK9890244

ABSTRACT

Varroa destructor mites are a primary driver of honeybee population decline, posing a serious threat to global agriculture due to their impact on pollination. Traditional detection methods, such as manual inspection and sticky boards, are labor-intensive and may disrupt hive activity. To address this, we developed a lightweight, real-time image classification system for early detection of Varroa infestations in honeybee hives using low-cost, embedded hardware. The system integrates a Raspberry Pi with a camera module and applies a convolutional neural network trained on 13,509 annotated images. We evaluated multiple architectures and found MobileNet-V2 to provide the best balance of accuracy and model size, achieving 80% accuracy with only 8.46 MB model size. The final model was converted to TensorFlow Lite format and deployed on Raspberry Pi and ESP32 devices, enabling offline inference and continuous, autonomous monitoring. This study demonstrates the feasibility of applying edge AI and transfer learning to support precision apiculture. It offers a scalable, cost-effective solution that can be expanded to broader applications in agriculture, environmental monitoring, and resource-constrained IoT settings.

Keywords: Varroa mite, honeybee, Raspberry Pi, edge AI, image classification, precision apiculture

INTRODUCTION

Honeybees (*Apis mellifera*) are essential pollinators responsible for approximately 75% of flowering plants and 35% of global food crop production [1]. However, recent declines in honeybee populations have raised significant concerns, driven by factors such as pesticide exposure, habitat loss, and pathogenic infestations. One of the most significant threats to honeybee health is the Varroa destructor mite, an external parasitic mite that feeds on the fat bodies near the belly of honeybees as shown in figure 2, compromising their immune system and spreading multiple viral pathogens. Varroa mites are considered a major cause of colony collapse disorder (CCD) and have been linked to increased bee mortality worldwide [2].

Several conventional methods exist for detecting Varroa infestations, such as manual mite counts using powdered sugar or alcohol washes, visual inspections, and the use of sticky boards. While these techniques can be effective, they are labor-intensive, time-consuming, and often require intrusive handling of the hive, which can further stress the bee colony [3]. Consequently, researchers have been exploring automated approaches, including image processing and machine learning models, to enable real-time, non-invasive Varroa mite detection. Deep learning methods have shown promise in detecting Varroa mites and monitoring hive health by utilizing object detection techniques [4].

This study focuses on developing a lightweight, real-time image classification model to detect Varroa mite infestations using a camera and microcontroller setup. The model was trained on a publicly available dataset of annotated honeybee images. To identify the most suitable architecture for real-time deployment, we evaluated several models, including MobileNet-V2, EfficientNet_Lite0, EfficientNet_Lite2, and EfficientNet_Lite4. Among these, MobileNet-V2 demonstrated the highest accuracy, achieving 80% precision with a compact size of 8.68 MB, making it ideal for deployment on devices with limited resources. The resulting system is optimized for field applications. It provides