Teleoperated 360° Video Capture of Beehives for Scientific Visualization in VR

Charles Ahn*
George Mason University
Fairfax, Virginia, USA

Ashaki SetepenRa-Deloatch
George Mason University
Fairfax, Virginia, USA

Ubada Ramadan
George Mason University
Fairfax, Virginia, USA

Quang Vo
George Mason University
Fairfax, Virginia, USA

Jacob Matthew Wojtecki
George Mason University
Fairfax, Virginia, USA

Nathan Alan Moy
George Mason University
Fairfax, Virginia, USA

Ching-I Huang
National Tsing Hua University
Hsinchu City, Taiwan

Bo Han
George Mason University
Fairfax, Virginia, USA

Songqing Chen
George Mason University
Fairfax, Virginia, USA

Carley Fisher-Maltese
George Mason University
Fairfax, Virginia, USA

Mohamed Alburaki
United States Department of Agriculture
Beltsville, Maryland, USA

Lap-Fai Yu
George Mason University
Fairfax, Virginia, USA

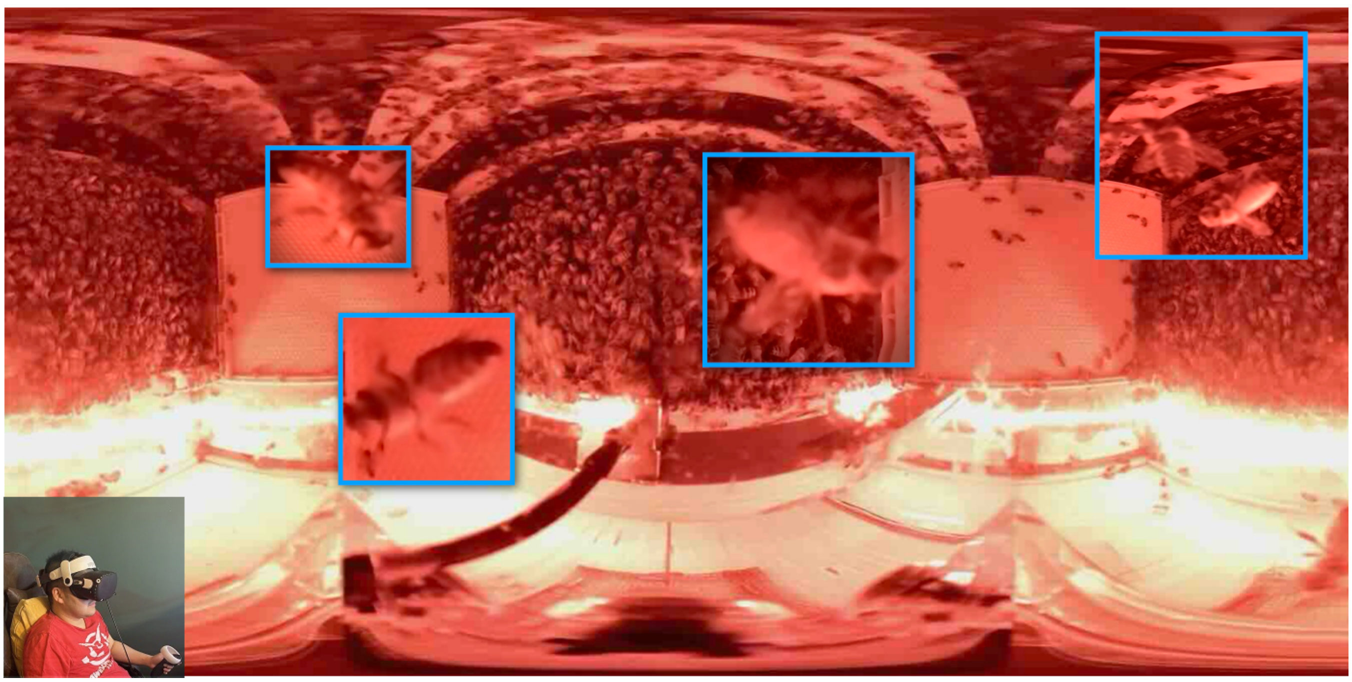

Figure 1: Bee clusters in a flattened 360° image captured by our system.

ABSTRACT

Studying bee behavior and diagnosing hive issues in their natural habitats has often been a challenge due to limited visibility, observer interference, and limitations of conventional recording methods. A teleoperated immersive 360° view offers an unobstrusive, holistic observation within the hive. In this work, we present a framework for capturing and analyzing bee activity using commercially available 360° cameras and hardware to create an immersive VR experience. A video demo is available at: https://youtu.be/96pqv9AyRlo.

KEYWORDS

Immersive 360°, Teleoperation, Virtual Reaility, Beehive

VRST '25, November 12–14, 2025, Montreal, Canada
2025. https://doi.org/10.1145/3756884.3768378

ACM Reference Format:
Charles Ahn, Ashaki SetepenRa-Deloatch, Ubada Ramadan, Quang Vo, Jacob Matthew Wojtecki, Nathan Alan Moy, Ching-I Huang, Bo Han, Songqing

Chen, Carley Fisher-Maltese, Mohamed Alburaki, and Lap-Fai Yu. . Teleoperated 360° Video Capture of Beehives for Scientific Visualization in VR. In *Proceedings of The 31st ACM Symposium on Virtual Reality Software and Technology (VRST '25)*. ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3756884.3768378

1 INTRODUCTION

Bees play a vital role in our ecosystem as key pollinators and contributors to food security. However, studying their complex social behaviors presents significant challenges due to their small size, sensitivity to light, and susceptibility to disturbance. Existing observation systems are limited. They either do not capture bees in their natural habitat (e.g., [1], [3]) or provide only a static generalized view of bees [2]. In this study, we created an immersive 360° system that allows students and researchers to observe bees with minimal disturbance.

2 SYSTEM DESIGN

The primary design objective was to provide users with a remote, holistic, and immersive view inside the beehive while ensuring minimal disruption to the bees. The immersive 360° hive system, as shown in Figure 2 is composed of several integrated components.

2.1 Mechanical Parts

The mechanical design involved modifying a standard deep super to create a square internal cavity for the bees. An inner cover was affixed to the super to serve as a lid, with an aperture cutout to house the Kandao Qoocam 8K Enterprise camera. The camera was enclosed in a weather-resistant hard case with a notched cutout for the power button, allowing a solenoid to remotely control the camera.

2.2 Network

Wireless connectivity was provided by a GL.iNet GL-E750V2 router (Mudi V2) with a pre-paid SIM card, connecting the Qoocam and a Raspberry Pi 5 for remote camera operation and data acquisition. Users can remotely access the Pi through the use of Raspberry Pi Connect screen sharing.

2.3 Electronics

The electronic system consists of a Raspberry Pi 5 (8GB of RAM) with a 2TB NVMe SSD, a 5V relay module, a power rail, and the router, all supported by an uninterruptible power supply. The relay module, connected to the Pi and power rail, enabled control of auxiliary devices including a fan, red LED light strip, and a solenoid. The Raspberry Pi operated on Raspberry Pi OS (64-bit Debian Bookworm), with a Waydroid container, which provided Android application compatibility on the Pi. This was required for communication with the Qoocam camera, as official support exists only for Android and iOS platforms.

3 DATA COLLECTION AND DEMO

Field trials yielded approximately 100 minutes of footage documenting behaviors such as brood care, comb construction, and in-hive interactions. The recordings were taken five times a day for a two-week period, though some sessions failed or were incomplete.

Figure 2: A beehive box equipped with our system.

Usable footage was transferred to a local workstation and viewed in virtual reality using Meta Quest Link with an Oculus Quest 2. Notably, the presence of a 360° camera did not appear to disrupt natural activity in the hive. The bees exhibited no observable signs of distress or avoidance of the equipment. These results suggest that immersive video can capture authentic behavioral patterns and provide a holistic view within the hive.

4 FUTURE WORK

The captured videos provide significant value by enabling repeated and detailed observation of bee behavior. Nevertheless, there are several limitations that we've identified.

For one thing, communication with the Qoocam requires an Android container, which introduces software bugs and inconsistencies, as well as degraded video quality. The system is also power-intensive and data-heavy, requiring continuous power and substantial storage capacity. We also observed some mechanical challenges, such as bees depositing wax on the camera casing, solenoid, and lights, which can impair solenoid function and disrupt remote camera operation.

This prototype serves as an initial testing platform, with ongoing efforts on integrating AI/ML techniques for video analysis and behavioral study during scientific visualization in virtual reality.

REFERENCES

[1] Bejamen Underwood William O'Brien Abdelbaset S. Hamza, Rahman Tashakkor and Chris Campbell. 2023. BeeLive: The IoT platform of Beemon monitoring and alerting system for beehives. *Science Direct* (2023). https://doi.org/10.1016/j.atech.2023.100331

[2] Dr.Biology. 2025. *Be a bee.* Retrieved Aug 25, 2025 from https://askabiologist.asu.edu/virtual-beehive

[3] Bernd Grünewald Paul Siefert, Natasya Buling. 2021. Honey Bee behaviours within the hive: Insights from long-term video analysis. *PLoS One* (2021).