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Identification of Foraging Bumblebees by Pulse Compression of their Unique Doppler Radar Signature

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Summary:

A technique for observing foraging bumblebees with a 24 GHz continuous-wave Doppler radar is described. Upon departing from the colony, we discovered that foraging bumblebees accelerate briefly at a constant 9.8 m/sec^2, resulting in a distinct, linear frequency modulated (LFM) radar return. By correlating this return with an expected LFM template, departing bumblebees could be identified and counted while arriving bumblebees and other environmental effects are rejected.

Keywords: Foraging bumblebee counter, Doppler radar, pulse compression, template correlation

Introduction

Commercial bumblebees are effective pollinators of greenhouse and field crops, but a colony only lasts a few months. This paper describes a sensor for monitoring the pollination effectiveness of a bumblebee colony by counting the number of daily flights of bumblebees with a Doppler radar. A typical radar installation on a bumblebee colony is shown in Fig.1.

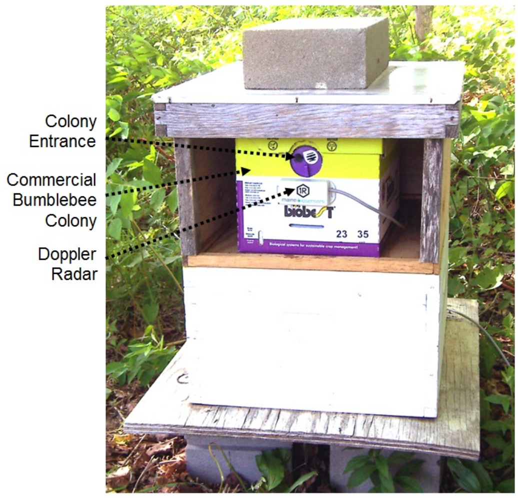

Fig. 1. Bumblebee colony with radar sensor

In a previous paper [1] on honeybees, we discovered that some honeybees departed the hive almost explosively, on a slightly ascending flight path, with a constant acceleration, quantitatively similar to gravitational acceleration. These bees were probably foragers looking for food in a distant location. We have observed the same behavior in less frequent flights of individual bumblebees. In [2], we exploited this characteristic to identify and count foraging bumblebees by applying a Hough transform to Doppler-Time-Images (DTI). Although the frequency-domain technique was successful, it exceeded a small, low-cost microprocessor's data storage and computational power. This paper uses the same Doppler radar [2] to implement an alternate, more straightforward technique of counting bumblebees based on template matching in the time domain.

Description of the New Method

We have shown in [1] that a 24 GHz Doppler radar, commonly found in automotive collision avoidance systems, can detect bees at a short distance. The unique acceleration characteristic of a foraging bee has a peculiar effect on the radar return. When a departing bee is illuminated by continuous-wave (CW) radar, the Doppler return from the bee is a nearly linear, frequency-modulated (LFM) waveform. For the 24 GHz radar, with λ = 12.5 mm and the flight parameters shown in Fig. 2, the Doppler frequency increases linearly from 0 Hz to 160 Hz in about 0.1 seconds.

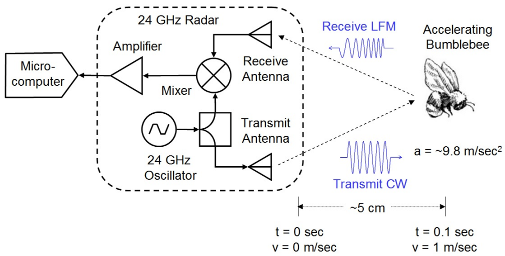

Fig. 2. Radar and bumblebee flight parameters

An LFM waveform, or chirp, is usually employed in a pulse compression radar to improve sensitivity and range resolution. Typically, the radar transmits an LFM waveform, receives an LFM waveform, and correlates it with an acceleration-corrected replica of the transmitted waveform [3]. The radar presented in this paper differs in that the radar transmits a CW signal, receives an LFM waveform, and correlates it with a synthetic LFM waveform based on the known target acceleration.

Results

We collected 24 GHz radar observations of bumblebees flying in front of a colony entrance by continuously recording the baseband signal in 19-sec segments at 800 samples/sec. A typical data file is shown in Fig. 3. More detailed pictures of departing (A, B) and arriving (C) bumblebees are shown in Fig. 4. The similarity of departing bumblebee radar returns is evident.

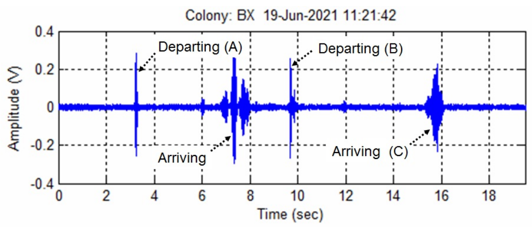

Fig. 3. Doppler radar baseband signal

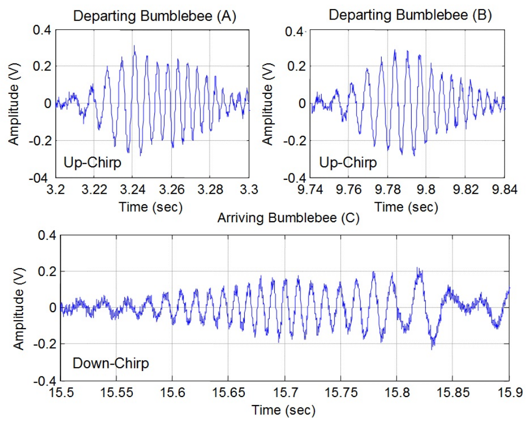

Fig. 4. Details of departing (A, B) and arriving (C) bumblebee Doppler radar baseband signals

We simulated a 0.1-sec 24 GHz Doppler radar return of a bumblebee departing with 9.8 m/sec^2 acceleration. The envelope of the simulated return was shaped to take the range geometry into account. A comparison of the Doppler return (A) with this template is shown in Fig. 5. We quantified the similarity between the two waveforms by Pearson's correlation coefficient, r = 0.86. This coefficient is independent of signal strength.

Due to differences in flight profiles, the measured departing bumblebee acceleration of 9.8 m/sec^2 had a standard deviation of 1.8 m/sec^2 [2]. Our technique is not particularly sensitive to the exact value of the actual acceleration. Setting a correlation threshold of r > 0.5 ensured correct identification of departing bumblebees.

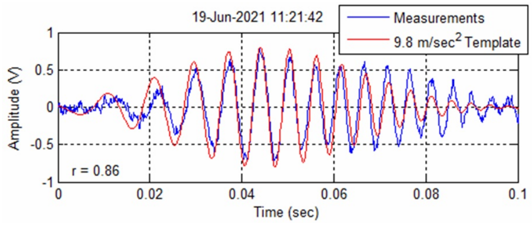

Fig. 5. Comparison of the departing bumblebee signal (A) with a 9.8 m/sec^2 acceleration template

Fig. 6 shows the correlation of the entire data segment depicted in Fig. 3 with the 9.8 m/sec^2 template in Fig. 5. Correlations with departing bumblebees are clearly above the threshold. In contrast, the correlations with arriving bumblebees are suppressed.

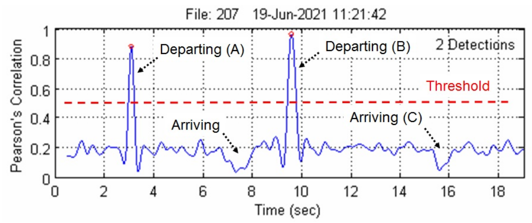

Fig. 6. Correlation of Doppler radar data in Fig. 3 with a 9.8 m/sec^2 acceleration template

We accumulated the count of departing bumblebee detections for each day from May to July 2021. Figure 7 illustrates the technique's effectiveness in monitoring the growth and decline of a bumblebee colony.

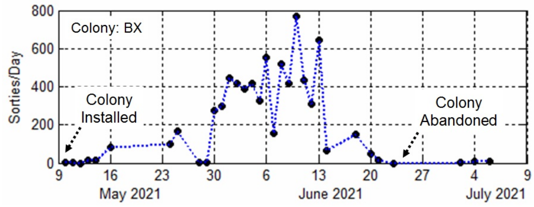

Fig. 7. Example of daily departing bumblebee counts

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