Real-Time Tracking & Enumerating of Flying Bees Using An Event-Based Vision Sensor

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HONORS COLLEGE

HIVE MIND

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Background: Bee Populations

Honey Bees (*Apis Mellifera*)

- Pollinators that contribute to crop reproduction and biodiversity [1]
- Vital part of local and global agriculture [2]
- Hives face increased pressure from pesticides, pests, and climate change

A bee infected by Varroa mites, a major threat to hive health

Hive Inspection

- Beekeepers inspect hives manually to monitor their health [3-4]
- Methods include:
  - Weighing hives
  - Modification for computer vision monitoring
  - Sound analysis
  - Tagging and mark/recapture
- All time-consuming and intrusive

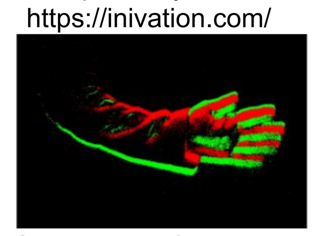
Bjerge et al, 2019 computer vision hive monitoring, restricting bees to crawling

[1] Ollerton et. al, 2011; [2] ISPP, 2016; [3] Barlow & Fell, 2006; [4] He et. al 2016

Dynamic Vision Sensor (DVS)

- Neuromorphic sensor designed by Inivation to mimic the behavior of a biological eye
- Pixels act as independent neurons capable of sending 2 signals: an up signal for increases in light levels and down signal for decreases
- Tracks **changes** in light intensity, not absolute value
- Signals are sent **asynchronously** as individual events
- Ideal for **fast-moving objects** on non-static background

DVXplorer by Inivation
https://inivation.com/



Screenshot of hand moving in front of DVS

Data Collection

- Monitor 3 UMD Honey Bee Lab hives
- Record simultaneous DVS output and webcam video to manually verify our algorithms
- A wooden apparatus ensures that the DVS and camera are aligned

Example of recording apparatus being used to track bees

Screenshot from the webcam video that operates parallel to the DVS

Tracking Algorithm

Time Surfaces

To detect the presence of a new bee, we track sudden increases in activity

- Divide screen into *k* by *k* pixel regions
- For each region, monitor a function S(t), given in discrete time by:

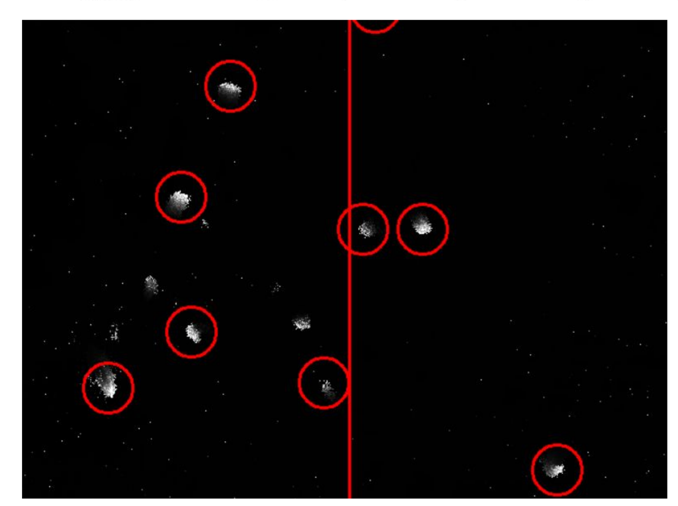
$$S_i(t+1) = e^{-1/\tau} S_i(t) + \sum_{x=-\frac{k}{2}}^{\frac{k}{2}} \sum_{y=-\frac{k}{2}}^{\frac{k}{2}} e_{x,y}(t)$$

- When S(t) crosses a threshold, a new bee tracking objecting is instantiated

Event-Based Tracking and Counting

- Each bee tracking object monitors a square region with side length 2*r*
- When a new event occurs at position $\mathbf{x_e}$ inside the region, the bee position and velocity are updated by:

$$x_{new} = \alpha\vec{x_e} + (1-\alpha)\vec{x} + \vec{v}(t - t_{prev}) \qquad \vec{v}(t) = (\vec{x}(t) - \vec{x}(t-1))/\Delta t$$



Left: Reconstruction of the image seen by the DVS based on its event stream. The red circles indicate detected bees. The vertical red line is a boundary used for counting; when bees cross the line, a counter is incremented. Bees are less likely to be detected closer to the hive where there is less contrast and they move at slower speeds
Right: Video of the entrance to the hive

Wingbeat Frequency Detection

Fourier Method

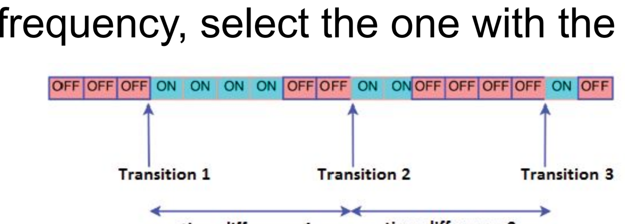
1. Extract time-varying 1-dimensional signal from the event stream of a bee
   a. To get a time varying signal, we looked at the difference between ON spikes (e_p) and OFF spikes (e_n):
   $$x(t) = \frac{\sum e_p - \sum e_n}{\sum e_p + \sum e_n}$$
2. Apply Discrete Fourier Transform to signal to determine frequency spectrum
3. The frequency with maximum DFT magnitude is the measured frequency

Forced Harmonic Oscillators

1. Model an oscillating system x(t) with target angular frequency ω, defined by:
   $$x(t) = Ae^{-\alpha t} cos(\omega t + \phi)$$
2. When a new event occurs at time t, the amplitude and phase are updated
   a. If the event occurs when dx/dt is near its maximum, the amplitude increases
3. Model an oscillator for every desired target frequency, select the one with the highest amplitude

Delay Timing

1. Extract a predefined marker measurement
2. Find repeated occurrences of the marker
3. Record time difference between occurrences
4. Example marker: OFF spike followed by ON spike



Pattern used in Hoseini and Linares-Barranco 2018. An OFF-ON transition is the "shape" the algorithm recognizes

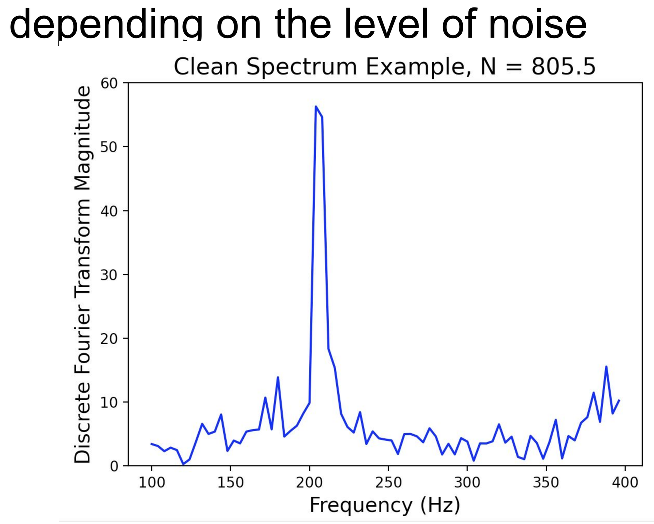
Results

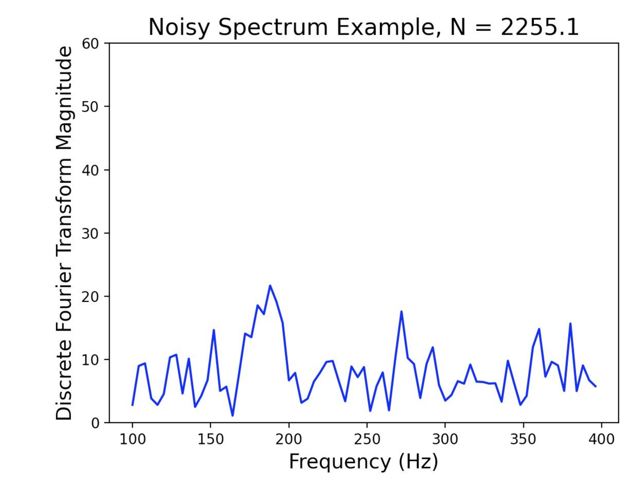
Tracking

- Counted **81%** of bees entering and **100%** of bees leaving over a 1 minute sample, for an average counting accuracy of **90%**

Wingbeat Frequency

- DFT magnitude spectra produced by the Fourier method vary greatly depending on the level of noise

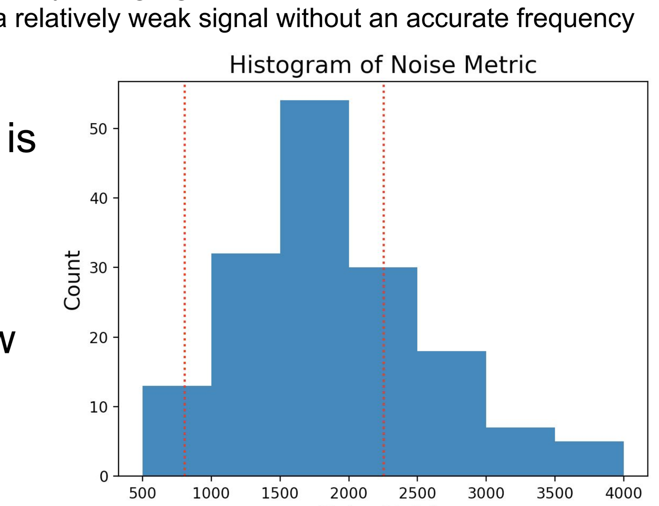




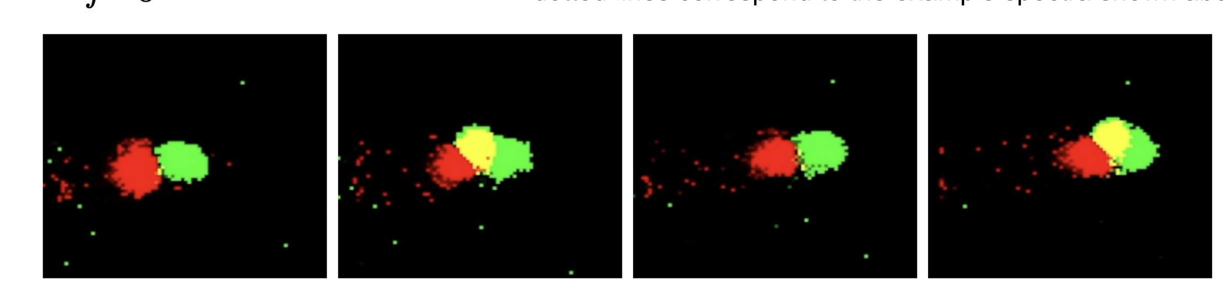
Left: A bee with a sole, high peak showing a relatively strong signal around 210 Hz.
Right: A bee with many distant peaks, showing a relatively weak signal without an accurate frequency

- We define a Noise Metric, N, to determine how noisy each spectra is
- The frequency can generally be determined if N < 2000
- Histogram shows that most bees have moderately noisy spectra; few are very clean or very noisy

$$N = \sum_{f=0}^{f_{max}} \frac{X[fT]}{X[f_{peak}T]}$$



Range of possible noise metrics for a sample of bees. The dotted lines correspond to the example spectra shown above.



Time surface accumulation of events generated by a flying bee. Green indicates an ON spike, red an OFF spike, and Yellow an ON and OFF spike in quick succession. The occasional flicker of successive spikes of different polarity indicate the beat of a wing

Future Research Goals

- Measure accuracy with various distances, lighting conditions, and backgrounds
- Collaborate with entomologists to track bee health metrics and population
- Conduct long-term live monitoring
- Write senior thesis and papers summarizing experiments and observations

Acknowledgements & References

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Launch UMD, Do Good Institute and UMD Libraries

Team Website