EBV: Electronic Bee-Veterinarian for Principled Mining and Forecasting of Honeybee Time Series

Mst Shamima Hossain\textsuperscript{1}  Christos Faloutsos\textsuperscript{2}  Boris Baer\textsuperscript{1}  Hyoseung Kim\textsuperscript{1}  Vassilis Tsotras\textsuperscript{1}

\textsuperscript{1}University of California, Riverside; \textsuperscript{2}Carnegie Mellon University, Pittsburgh

Registration and travel support for this presentation was provided by the Society for Industrial and Applied Mathematics
Outline

- Motivation & Background
- Method & Technical Solution
- Empirical Evaluation
- Conclusion
Outline

- Motivation & Background
- Method & Technical Solution
- Empirical Evaluation
- Conclusion
Motivation

Billion Dollar Industry + Higher Colony Loss + No Bees, No Humans = Reliable & Explainable Hive Monitoring System

(2022 - 2023)
Background (1/3)

Hive temperature gives valuable information about hive health.

Core Area
(Near brood nest area)
Most Important!

Peripheral Area
(Near honey storage area)
Background (2/3)

\[ 33^\circ C \leq \text{Core Temp}, \ \Theta(t) \leq 36^\circ C = \]

\[ \Theta(t) \leq 33^\circ C \ \text{or} \ \Theta(t) \geq 36^\circ C = \]
Background (3/3)

Think of hive core temperature as human body temperature….

Change in thermoregulation ability = 1st order response to stressors

Cooling during Heat + Heating during Cold = Thermoregulation

SDM 24 MS. Hossain et al.
Problem Statement

GIVEN:

- **G1**: Quantify Bee Strength
- **G2**: Detect & Explain Events
- **G3**: Forecast

DO:
## Related Work

<table>
<thead>
<tr>
<th>Property</th>
<th>Poor Performance (rule based: arbitrary threshold)</th>
<th>Blackbox &amp; Domain agnostic</th>
<th>Unsupervised</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>Hive monitoring and analysis</td>
<td>Traditional time series</td>
<td>Deep Learning</td>
</tr>
<tr>
<td>C1: domain-specific</td>
<td>✔</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>C2: effective</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>C3: explainable</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>C4: scalable</td>
<td>✔</td>
<td>✔</td>
<td>?</td>
</tr>
</tbody>
</table>


SDM 24

MS. Hossain et al.
Contributions: EBV

Addresses limitations of prior work

\( \nabla^2 \theta \propto \partial \theta / \partial t \)

\( \Delta s_c = -82\% \)
\( \Delta s_h = -55\% \)

**C1: Principled**
- Thermal diffusion
- Control Theory

**C2: Effective**
- Forecasting with high accuracy

**C3: Explainable**
- Hive strength parameter
- State discontinuity detection

**C4: Scalable**
- Linear with input size

**C5: Informative**
- In line with domain experts

MS. Hossain et al.

SDM 24
Outline

- Motivation & Background
- **Method & Technical Solution**
- Empirical Evaluation
- Conclusion
Dataset & Experimental Setup

Peripheral Area
(Near honey storage area)

Core Area
(Near brood nest area)

Riverside, California, USA (Aug’21 - Sep’21)

Challenge: Very hot climate → Severely stressed hives

Probable Solution: Add ice cubes on top of hives
Recorded Temperature Data

Control Hive
(5 in total)

Treated Hive
(5 in total)

Core Temperature Varies More in Control Hives !!
Overview of Proposed Method: EBV

1. \( \text{EBV}_{\text{model}} \): Reconstruction
   
   \( G1: \) Quantify Bee Strength &
   
   \( G3: \) Forecast

2. \( \text{EBV}_{\text{fit&cur}} \): Segmentation
   
   \( G2: \) Event Detect.

\[ \Delta s_c = -82\% \]
\[ \Delta s_h = -55\% \]
\[ \frac{\partial \theta(t)}{\partial t} = \begin{cases} \theta_{ext}(t) + \theta_{adj}(t) - 2\theta(t) & \text{if } \theta_{ext}(t) \geq 0 \\ \theta_{ext}(t) + \theta_{adj}(t) - 2\theta(t) & \text{otherwise} \end{cases} \]

**Heat Flows**

\[ \nabla^2 \theta \propto \frac{\partial \theta}{\partial t} \]

**Environment**

\[ \text{Env. Temp. } \propto \text{Hive Temp.} \]

**Physics:**

**Thermal Diffusion**

**Control Theory:**

*Split* P-Controller

\[ \text{Hive Temp. } \propto \text{Required bees’ work} \]

**Details**

- Cooling: Strength, \( s_c \)
- Heating: Strength, \( s_h \)

\[ \text{Set Point: } \Theta_{\text{ideal}} \]

SDM 24

MS. Hossain et al.
Hypothesis: Bees’ strength will not change \((\text{segment})\) unless there are any stressors \((\text{cut-point})\).

Q: How to find segments and cut-points?

A: (a) Occam's Razor: Simple & Accurate  
   (b) Greedy Algorithm: Fast Execution

S1: Represent the sequence with no cuts \((m=0)\) & one set of params \((p=3)\)

\[
X_0 = (s_c, s_h, \Theta_{\text{ideal}}) \quad \text{AIC}_0 = -2\ln L_0 + 2(m + (m+1)p)
\]

Accuracy \quad \text{Model Complexity}
Segmentation Algorithm: EBV$^{\text{fit&cut}}$ (2/2)

Q: How to find segments and cut-points? (cntd…)

S2: Now try with a single cut and two segments

\[
AIC_1 = -2\ln L_1 + 2(m + (m+1)p); \ m = 1, \ p = 2*3 = 6
\]

Compare: (AIC$_1 < AIC_0$) ? If TRUE:

S3: Repeat Till Find Best Reconstruction with \textit{Minimum AIC} !!
Outline

● Motivation & Background
● Method & Technical Solution
● **Empirical Evaluation**
  ○ Q1 Effective: (a) Forecasting ($G_3$) & (b) Event Detection ($G_2$)
  ○ Q2 Explainable: (a) Event Detection ($G_2$) & (b) Treatment Effect ($G_2$)
  ○ Q3 Scalable: Linear on input size
  ○ Q4 Informative: Observation coincides with experts ($G_2$)
● Conclusion
Q1(a) Effective: Forecasting (G3)

Input (3 days) → Forecasted (7 days)

Control Hive
Q1(a) Effective: Improved Accuracy ($G_3$)

**Treated Hive**

**Control Hive**

![Bar chart showing forecast error (RMSE) for different models: DeepAR, ARX, Seasonal ARX, Holt-Winters, EBV. The chart compares the performance of these models between the treated and control hives. The treated hive shows a 49% improvement in accuracy compared to the control hive, which shows a 21% improvement.](chart.png)
Q1(a) Effective: Improved Accuracy (G3)

Treated Hive

Control Hive

49%

EBV wins!!

21%
Q1(b) Effective: Event Detection (G2)

Control Hive

Discontinuity

Hive Inspection

Sensor Recharge & Replace

11 days

8 days
Q1(b) Effective: Event Detection (G2)

Control Hive

Discontinuity

Hive Inspection = Dead/injured Larvae
Exhausted Bees

11 days
8 days

Recharge & Replace

Weak

Strong

Mixed

8 days
11 days
Q2(a) Explainable: Event Detection (G2)

Strength of cooling, $s_c = 55$

Strength of heating, $s_h = 31$

$\Delta s_c = +38\%$

$\Delta s_h = -35\%$

$s_c = 76$

$s_h = 20$

$\Delta s_c = -82\%$

$\Delta s_h = -55\%$

$s_c = 14$

$s_h = 9$

Hive Inspection + Sensor Recharge & Replace

Control Hive

11 days

8 days
Q2(b) Explainable: Treatment Effect ($G2$)

<table>
<thead>
<tr>
<th>Control Hive</th>
<th>Treated Hive</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta s_c = +38%$</td>
<td>$\Delta s_c = -82%$</td>
</tr>
<tr>
<td>$\Delta s_h = -35%$</td>
<td>$\Delta s_h = -55%$</td>
</tr>
<tr>
<td>$\Delta s_c = -40%$</td>
<td>$\Delta s_c = -40%$</td>
</tr>
<tr>
<td>$\Delta s_h = -48%$</td>
<td>$\Delta s_h = -48%$</td>
</tr>
</tbody>
</table>

**Ice Applied**

[Graph showing temperature changes over time for Control and Treated Hive with Ice Applied]
Q2(b) Explainable: Treatment Effect (G2)

\[ \Delta s_c = +38\% \]

\[ \Delta s_h = -35\% \]

\[ \Delta s_c = -82\% \]

\[ \Delta s_h = -55\% \]
Q3 Scalable

- **Linear & Fast**: 20 min for 2 months of data
- **“Embarrassingly Parallel”**
Observation (1):
Heating is easier than cooling
\((s_h > s_c)\)
Observation (2):
Bees in treated hives are stronger, i.e. better thermoregulation.
Observation (3):
Positive Cumulative Effect of Ice Treatment

Control (= un-treated) hives suffer more from hive-openings.
Outline

- Motivation & Background
- Method & Technical Solution
- Empirical Evaluation
- Conclusion
THANK YOU!!

github.com/rtenlab/EBeeVet

C1: Principled

C2: Effective

C3: Explainable

C4: Scalable

C5: Informative
THANK YOU!!
github.com/rttenlab/EBeeVet

**C1:** Principled

\[ \nabla^2 \theta \propto \frac{\partial \theta}{\partial t} \n\]

**C2:** Effective

**C3:** Explainable

**C4:** Scalable

**C5:** Informative

Registration and travel support for this presentation was provided by the Society for Industrial and Applied Mathematics

Contact:
mhoss037@ucr.edu

**Ongoing Work:**
Real-time notification of honey bee health