Year 5: Engineering a Novel IoT Trapping System with a Multiple Linear Regression Model Towards Eco-Friendly, High-Efficacy, Low-Cost Honey Bee Pest Treatment and Management

Introduction

- Honey bees (*Apis mellifera*) perform **80% of global crop pollination** and **contribute $183 billion to the global economy annually**. However, US commercial hives are dying at an alarming rate of ~ 50% annually.
- The **small hive beetle (SHB),** *Aethina tumida*, is a **major, virulent pest of the honey bee**. SHBs are new, invasive, and reproduce uncontrollably causing hive death in a mere week if not treated. SHBs consume bee eggs, brood, pollen, and honey, defecate in the hive, and transmit many diseases.
- SHBs also significantly stress both strong and weak hives, greatly worsening the effects of external stressors such as malnutrition, pesticides, immunodeficiencies, inadequate foraging availabilities, and climate change which ultimately kills bees.
- Presently, leading SHB treatments are chemical-based, such as the leading commercial and **only EPA-approved in-hive chemical treatment: coumaphos**. Coumaphos poses significant health and environmental risks. High coumaphos traces (up to 98%) have been found in honey, wax, and propolis.

Background

Research Background: For the first three years, this project focused on developing a highly effective, low-cost, and organic alternative to pesticides for SHB treatment. **A novel blend bait was created based on the volatile composition of beer.** The treatment was successfully tested in the lab setting, field setting, and even in a comparative field trial against coumaphos, the leading commercial pesticide for SHB treatment. **The blend proved equally as effective as coumaphos while being 4754 times cheaper.**

Research Problem: After surveying multiple beekeepers, another problem emerged. Despite its high-efficacy and low-cost, the blend (and all existing SHB treatments) require significant field labor and are time intensive. Moreover, they do not provide beekeepers insight into long-term hive-health which can lead to poor pest management and weak/dead hives. They also lead to material waste due to their highly disposable nature.

Research Claim

CURRENT PROJECT CLAIM

This year's focus was developing an easy-to-use system (using the previously developed blend) that also provides data on future pest infestations. A 3D-printed IoT trap was engineered to store the attractant blend. This trap automatically records SHB capture counts and is reusable, reducing field labor and cost. A multiple linear regression (MLR) model was also developed to analyze SHB counts from the IoT trap instantly. The algorithm predicts future SHB counts. An iOS application is being developed to personalize integrated pest management (IPM) plans for any hive scenario. This system is called **BeetleGuardAI.**

Methodologies

1) **IoT Device Engineering** → **2) IoT Device Testing**

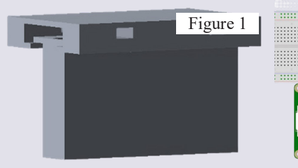
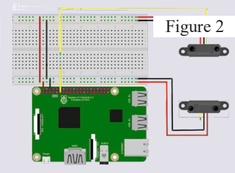


Figure 1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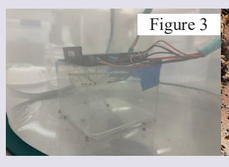


Figure 3

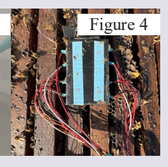


Figure 4

3) MLR Model Development → **4) MLR Model Evaluation**

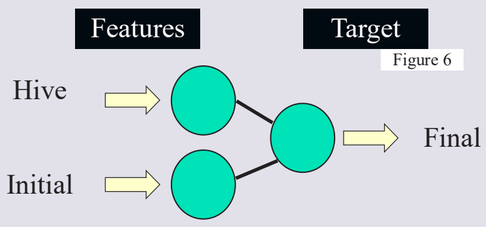
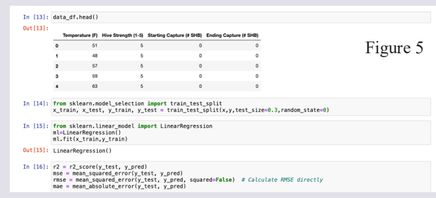


Figure 6



```
In [13]: data_df.head()
Out[13]:
   Temperature (F)  Hive Strength (1-5)  Starting Capture (# SHB)  Ending Capture (# SHB)
0               51                    5                         0                       0
1               48                    5                         0                       0
2               57                    5                         0                       0
3               59                    5                         0                       0
4               63                    5                         0                       0

In [14]: from sklearn.model_selection import train_test_split
         x_train, x_test, y_train, y_test = train_test_split(x,y,test_size=0.3,random_state=0)

In [15]: from sklearn.linear_model import LinearRegression
         mlr=LinearRegression()
         mlr.fit(x_train,y_train)
Out[15]: LinearRegression()

In [16]: r2 = r2_score(y_test, y_pred)
         mse = mean_squared_error(y_test, y_pred)
         rmse = mean_squared_error(y_test, y_pred, squared=False)  # Calculate RMSE directly
         mae = mean_absolute_error(y_test, y_pred)
```

Figure 5

Results

Fig 7: In-Vitro Trap Testing Assays

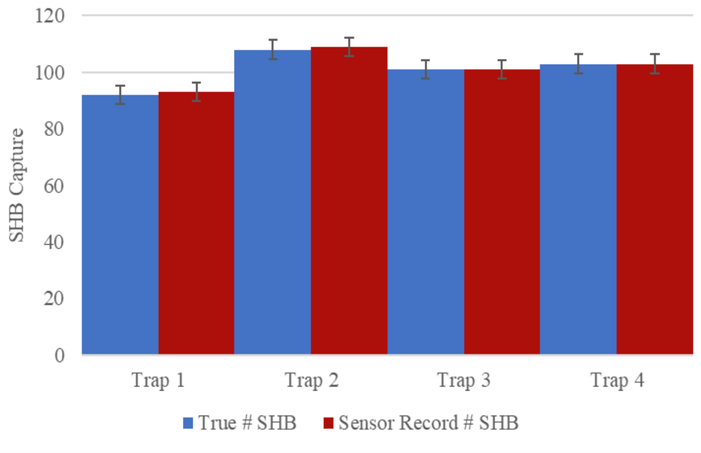


Fig 8: Field Trap Testing

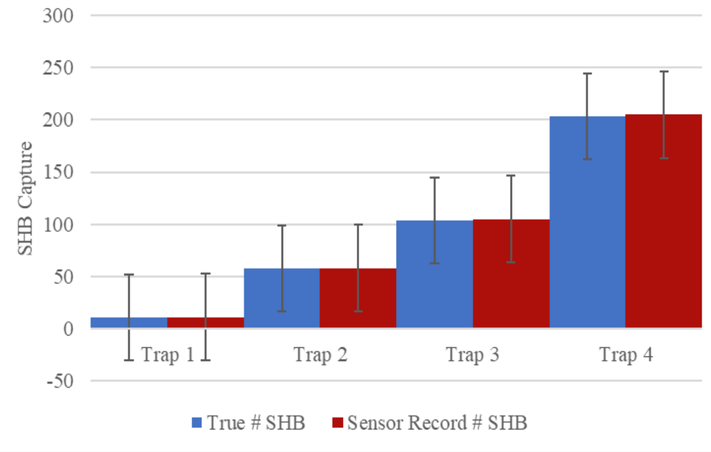


Fig 9: Field Trial Raw Beetle Capture Data

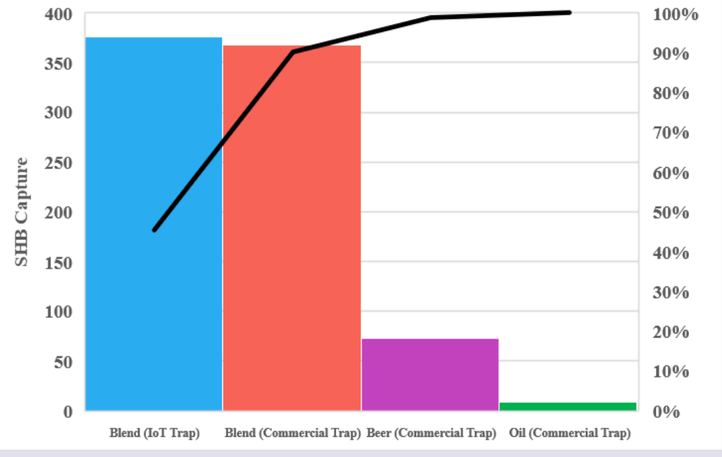


Fig 10: True Capture vs. MLR Predicted Capture

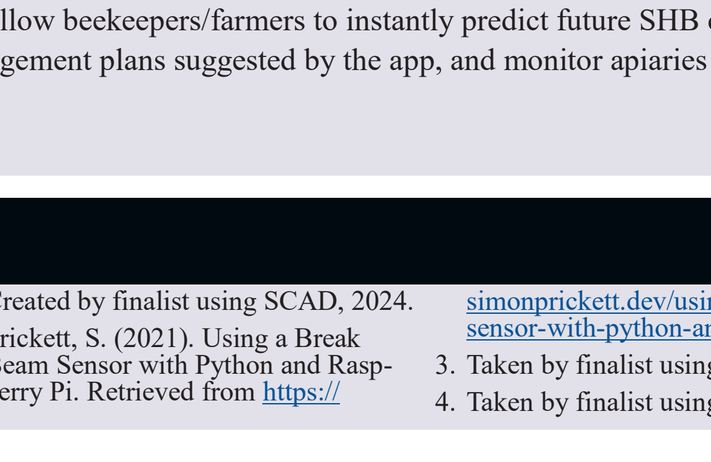


Fig 11: Histogram of MLR Residuals

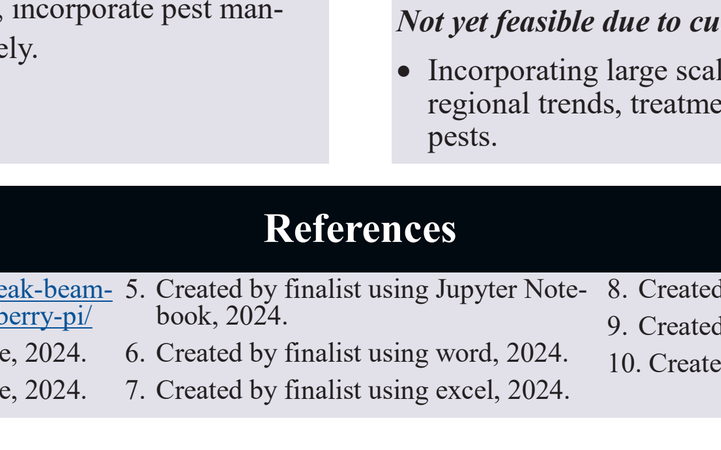
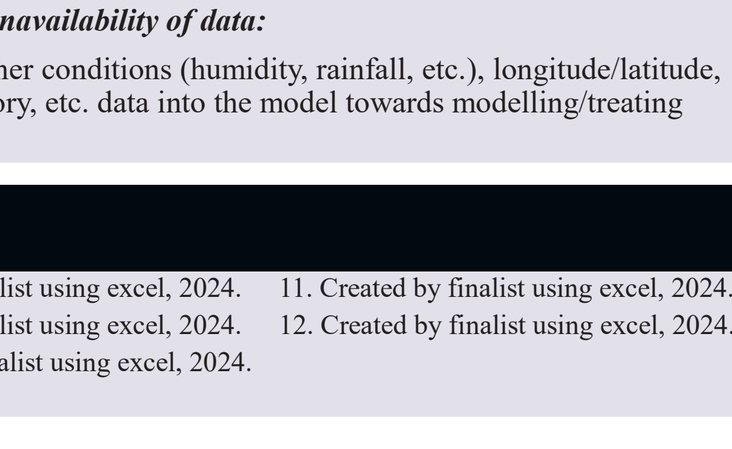


Fig 12: Root Mean Squared Error Over Time



Conclusion

- The data indicate that **BeetleGuardAI** can treat pest infestation just as effectively as the leading pesticide with high-accuracy while providing insight into future hive health. Coumaphos (gold standard for SHB treatment) has many health, environmental, and hive contamination risks. BeetleGuardAI is 4754X cheaper than coumaphos, saving the global industry $5.2 billion annually. This technology poses none of these risks and is **(1) low-cost (2) easy-to-use (3) eco-friendly and (4) personalized to each hive scenario.**
- After speaking with multiple beekeepers, it became apparent that a centralized dashboard to monitor **BeetleGuardAI** would be useful. To satisfy this need, the blend, IoT trap, and MLR model are currently being integrated into a user-friendly iOS application. This will allow beekeepers/farmers to instantly predict future SHB counts, incorporate pest management plans suggested by the app, and monitor apiaries remotely.

Future Work

I'm very excited about the positive results I have achieved thus far. I have lots of ideas about future investigation and studies I want to conduct next!

- Applying **continual learning** (CL) algorithms for real-world adaptation such as the changing climate/condition of an apiary with beehives.
- Expanding the model into a Recurrent Neural Network (RNN) to account for **environmental stressors, temporal dependencies, and dynamics** while predicting future SHB populations.
- Creating wireless trap devices that have cellular capabilities to allow for large-scale remote monitoring. Using this system, a beekeeper/farmer would receive SMS text notifications regarding pest infestation levels directly from the mobile application at any location.

Not yet feasible due to current unavailability of data:

- Incorporating large scale weather conditions (humidity, rainfall, etc.), longitude/latitude, regional trends, treatment history, etc. data into the model towards modelling/treating pests.

References

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2. Prickett, S. (2021). Using a Break Beam Sensor with Python and Raspberry Pi. Retrieved from https://simonprickett.dev/using-a-break-beam-sensor-with-python-and-raspberry-pi/
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