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Cognitive Integrated Sensor Systems for In-Hive Varroa Infestation Level Estimation based on Temperature-Modulated Gas Sensing

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Summary:

Bees are recognized as an indispensable link in the human food chain and general ecological system. Numerous threats, from pesticides to parasites, endanger bees and frequently lead to hive collapse. The varroa destructor mite is a key threat to bee keeping and the monitoring of hive infestation level is of major concern for effective treatment. Sensors and automation, e.g., as in condition-monitoring and Industry 4.0 with machine learning offer help. Here, from our **IndusBee4.0** project, an integrated in-hive gas sensing system, denoted as **BeE-Nose**, for infestation level estimation and its application to a colony in the bee season 2020 from July to September is presented with first results of varroa infestation level estimation and automated treatment need detection.

Keywords: Temperature-modulated gas sensor, varroa infestation level, treatment need detection, digital bee keeping, in-hive measurement, cognitive sensor systems

Introduction

Major issues from environmental pollution to invasive species are threatening our ecological system and the human food supply. Insects, and honey bees in particular, play a decisive role, e.g., for pollination. The varroa mite parasite is a major threat to bee keeping and the cause of many bee colony losses. The monitoring of the varroa infestation level is one important task of conventionally operating bee keepers. Though there is a community practicing treatment free bee keeping [1], the majority of bee keepers follows standard treatment practice, e.g., by formic acid, which needs to know the right time to start treatment based on the hive infestation level. Sensors and automation, like in home automation, condition-monitoring and Industry 4.0, can both alleviate hive keeping and also make it much more effective. Thus, in the last 10-15 years numerous approaches to digital bee keeping can be observed [1]. In our **IndusBee4.0** project, small, effective, and affordable cognitive integrated sensor systems for continuous in-hive-monitoring and state estimation, e.g., monitoring and reporting the varroa infestation level, are pursued. In particular, integrated gas sensors, e.g., the BME680, are investigated for this purpose in the following.

Conventional Varroa Monitoring Methods

There are several standard methods available for conventional varroa infestation level estimation (VILE). They all have in common, that they imply substantial effort for the bee keeper and deliver results only at larger time steps. The analysis of hive debris including mites, dropping from the hive bottom and collected on a slider or varroa board, is most common. Usually, three days are expended until a manual, or more recently (semi) automated vision-based analysis, of the debris for the number of varroa can be conducted. The hive infestation level can be estimated from this count [1]. Another common approach, also denoted as flotation method, extracts a bee sample from the hive and drowns them to separate bees and varroa. The powder sugar and the CO_2-based sedation are two alternative more bee-friendly variants. Again, hive infestation level can be estimated from the count. Sample adequateness will probably depend on the location of extraction in the hive. More recent principle approaches try to scrutinize in and out going bees at the flight hole for varroa mites clinging to them, e.g., [3, 1]. In this paper, the standard counting on the varroa board will be applied to obtain the required ground truth for VILE and the automated treatment need detection (ATND).

Indirect Gas Sensor-Based VILE

Basic investigations in the past have revealed, that both the sound patterns emitted by bees as well as the air composition inside the hive host information, that correlates with the varroa infestation level, as determined by the conven-

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tional methods from the previous section. Hive sound patterns also allow to detect hints on 'missing queen', advent of 'swarming mood' etc. Thus, in our and many others previous work, microphones and signal processing and analysis have been applied, see e.g., [1]. MEMS microphones deliver in our Pi Zero W based **SmartComb** in-hive measurement system [1] the acoustical information on hive state, including continuous cues for VILE. Recent intriguing work, based on a set of Figaro gas sensors and an external measurement system confirmed the existence and usefulness of a correlation of hive air analysis results and varroa infestation level [2] [4]. With the advent of highly integrated gas sensing systems, e.g., Sensirion SGP30 multi-pixel sensor system [1] or the BOSCH Sensortec BME680, the possibility of VILE by in-hive low-cost gas sensing system and direct or indirect indicators from hive air analysis over the bee season was added to our **IndusBee4.0** system. **Fig. 1** shows the **SmartComb** measurement systems, non-obtrusive to the bees, and continuously delivering registrations at any desirable rate, with the **BeE-Nose** extension in stable 'bee climate'.

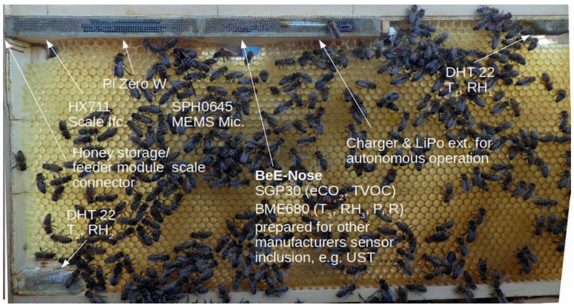

Fig. 1. ***SmartComb*** *with SGP30 and BME680*

The BME680 allows the control of sensor heating, i.e., it can be modulated for temperature cycles in measurement (Virtual sensors).

Experiments and Results

One **SmartComb** module (as exemplified in **Fig. 1**) has been deployed in a mature hive, that had released as swarm, and data (T, RH, weight, hive sound, and gas sensor data from hive air) from July to September until formic acid treatment, has been collected. **Fig. 2** shows gas sensing results complemented with varroa counting data as ground truth for this campaign. A subset of this data has been sampled in a train and a test set with 1047 samples each and 8 measurements from a temperature modulation with 8 equidistant levels from 50° C to 400° C have been employed as raw features for the first VILE and ATND. For VILE, four classes, *No_Varroa*, *Low_Varroa*, *Mid_Varroa*, *Treatment_!*, have been introduced.

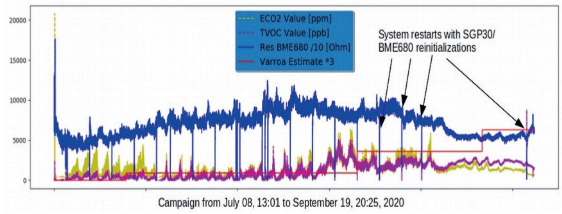

Fig. 2. Three months of SPG30 eCO_2, TVOC, & BME680 resistance data @400° C with varroa count.

For ATND, the first three classes are merged to *SubTh*. **Fig. 3** shows a scatter plot of the first two BME680 T-modulated outputs.

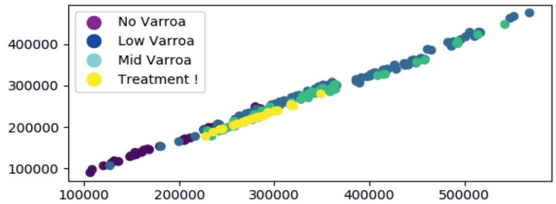

Fig. 3. BME680 resistance data scatter plot of first two of 8 T-modulated channels with four classes.

Fig. 3 shows only a weak support for the VILE. A kNN classification of all 8 channels with k=3 gave 83,73 % resubstitution and 70.33 % generalization recognition rate. For the two classes of ATND and the selected BME680 channels 2, 6, 7, and 8, resubstitution of 91.86 % could be achieved with 99.25 % for 934 *SubTh* and 92.3 % of 113 *Treatment_!* true positive patterns.

Conclusions

Honoring the importance and challenging of honey bees, an in-hive close to brood nest sensing system has been applied for a substantial time of the 2020 bee season. First VILE and ATND results on indirect hive air cues were obtained. Validation, robustness investigation, and multi-sensing is required next. The approach is potentially generalizable to foulbrood, SHB etc.

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