Sensor Study for Monitoring Varroa Mites on Honey Bees (*Apis mellifera*)

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***Abstract*—Rapid growth of parasites like *Varroa destructor* is one of the main reasons for elevated mortality of bee colonies. Beekeepers have to perform time consuming manual sampling and treatment to avoid colony losses. This work proposes a camera system, which can be mounted at the entrance of a standard honey bee hive and it is part of a two year ongoing project. The goal is to find a camera setup for detecting bees infected with *V. destructor* mites when they are entering or leaving, giving real time estimations of the *V. destructor* population inside the hive. To check the feasibility of the project a prototype was designed, implemented and tested. Recommendations for the automatic detection of Varroa mites are discussed and presented.**

I. Introduction

Within the last decades, the global spread of the parasitic mite *Varroa destructor* has resulted in the loss of millions of honey bee (*Apis mellifera*) colonies [1]. There is general consensus that the mite and its vector capacity for a range of honey bee viruses is a contributing factor in the global phenomenon of overwintering losses and elevated honey bee colony mortality [2].

V. destructor have specialized their life cycle around the honey bee, by laying their eggs inside a bees brood cell before it is closed with a wax capping [3]. There the growing mites feed on the larva, weakening but not killing their host. This is important, so the bee can still chew its way out of the wax capping and release the parental mite and its offspring. They will again find new brood cells and the circle starts over again. The weakening from mite feeding results in a reduced life span of the host, but more drastically they transmit a variety of viruses. The symptoms are disoriented or crippled bees, which are unable to fly. The weakening of the colony again helps mites to spread to other bee hives mediated by cleptoparasitism. The presence of these viruses has been strongly linked to colony losses [4].

The straight-forward method for detecting a *V. destructor* infestation is regular manual sampling, which is state of the art [5]. There are three types of tests that can be performed:

- Sampling from living bees: a sample of 500 to 1,000 bees is put into a jar with alcohol or powder sugar and it is shaken until most mites fall off. Depending on the exact method most bees are injured or die due to this procedure.
- Sampling the brood: opening brood cells and checking for mites. This also kills the brood.
- Noninvasive sticky board: a board covered with Vaseline is put at the bottom of each bee hive to monitor the natural mite drop inside the hive.

All methods have two drawbacks in common: they can only provide statistical estimations upon the sampled data and they are time-consuming to perform, especially when done in high frequencies. For these reasons, the possible benefits of an automatic camera system mounted at the entrance of the bee hive are evident. It would offer a real-time analysis of the provided video stream for a more accurate up-to-date estimation of the mite population, without manual interaction. In this paper, we present a study of a first prototype of such a camera system with the goal of automatic Varroa mite monitoring[1]. There is a strong need for automatic parasite monitoring since colony loss is an acute problem. Early recognition and effective treatment can prevent major damage and reduced colony mortality.

II. Related Work

Automatic health monitoring of honey bees is already available on the market, with products like *ARNIA*[2], *HOBOS*[3] or the *BeeHive Lab project* [6]. But they all focus on general parameters like temperature or weight to determine the bees productivity. To the best of our knowledge, no visual system designed for parasite monitoring has been proposed in the past. In [7] a system is presented which detects differences in the sound spectra the bees produce when they start to get sick with parasites. However, the study could not give accurate estimations for real world performance.

In [8] image processing is used to monitor mites within brood cells. The paper focuses on tracking the mites inside the cell and tests are done only in a laboratory environment.

Similarities to our work can be found in [9], concerning the general test setup and the construction of the video system. The presented system measures the in-and-out activity of bees using a camera module mounted at the entrance of a bee hive. However, in contrast to our system their goal was to recognize individual bees by sticking small tags to the back of each bee. Then optical character recognition was performed to recognize the tags.

[1] project homepage: http://www.caa.tuwien.ac.at/cvl/project/mic-cam/
[2] http://www.arnia.co.uk/ (last visited: 3rd October, 2016)
[3] http://www.hobos.de/ (last visited: 3rd October, 2016)

(a) (b)

Fig. 1. (a) OpenSCAD 3D model of the prototype. All yellowish areas are cut out of wood and the gray semi-transparent ones are cut out of acrylic glass. The box on top is mounted with screws and is adjustable in height. The camera will be mounted on the bottom of the box facing towards the acrylic glass of the tunnel. (b) A picture of the final prototype which was used to produce the videos and images presented. It is mounted at the entrance of a bee hive floor. The lighting and the camera box are adjustable in height to be able to fine tune the field of view and the overall light intensity.

III. Monitoring System and Prototyping

There are general requirements for the monitoring system to be created:

- **Non-invasiveness**: most important is that bees are not disturbed in their daily business when the system is in use.
- **Easy mounting**: by creating a system that is flexible enough to work with typical bee hives found on the marked today makes it able to be applied on a wide scale basis.
- **Cost efficiency**: The selected hardware should be affordable to again support a wide scale application of the system.

There are other factors like weather resistance, small dimensions, portability etc. which are important. Additionally, it should be a stand alone solution, meaning that there are no extra computers necessary for monitoring. To check the feasibility of the project, a prototype was designed and built.

To address the issue of easy mounting a market standard bee hive was used to deal with overall dimensions. This hives entrance is approximately $37cm$ wide and $4cm$ high. For simplicity reasons a setup with only one camera was used, although multiple cameras would be possible. And since this camera has a limited field of view the entrance of the hive needed to be narrowed to get enough details.

This led to the design depicted in Figure 1. It is equipped with a camera at the top and a passageway with a transparent roof. The camera is mounted at the entrance and all other entrances are covered, so that if a bee wants to enter or leave the hive it has to pass the camera. The overall design of this passageway is based on the findings of [9]. There they take the main tunnel and split it into smaller ones of 8mm width, so that only individual bees can pass. These small sub-tunnels make tracking a lot easier, since bees now can only enter a tunnel one after another and the walking direction is predefined.

The prototype was designed using OpenSCAD, which is a solid geometry operations based programming language for generating CAD models. A rendered image of the model is shown in Figure 1a. Notches were added at junctions of connecting planes to add stability and ease final assembly. The 3D design was cut out of wood and acrylic glass using a laser cutter machine. Then the lighting, camera and micro computer were mounted. Figure 1b shows a picture of the final and fully assembled prototype.

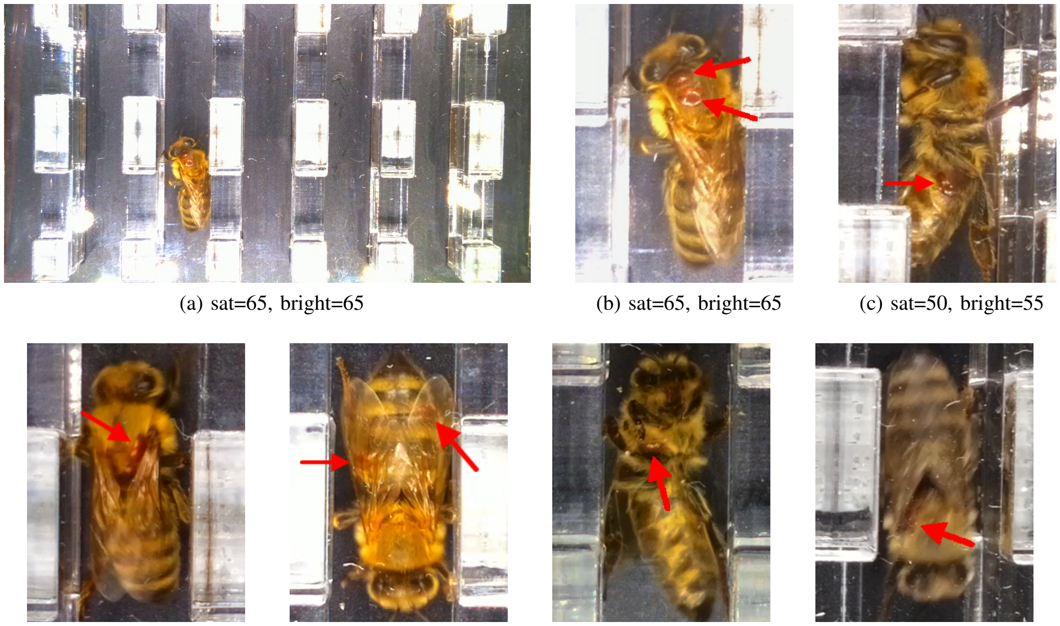
For video processing a micro computer *Raspberry Pi 3 Model B* was used, which is equipped with a 1.2 GHz quad-core and 1GB of RAM. The Raspberry Pi is perfectly suitable for prototyping tasks, since there exists a huge community with lots of documented applications using a camera setup. Additionally, the energy consumption is low and the price is very reasonable ($\leq$ 40 USD, July 2016). It was used in combination with the *camera module v2.1* which is an affordable camera solution for the Raspberry Pi ($\leq$ 30 USD, July 2016). All interactions with the camera module can be done using an open Python library. Downside of the camera is its fixed focus of about 1m to infinity. To get sharp images at a field of view covering the tunnel area the focus had to be set to about $12cm$. The lens of the camera module is threaded on top of the sensor and the focus can be changed by turning the lens. The resulting field of view is $7.3cm$ wide and $4.1cm$ high at a resolution of 1920x1080 pixels.

IV. Experiments

At the time of testing a high density of *V. destructor* was found at the observed hives. Infected bees were taken and locked inside the prototype to produce as much footage as possible. Example frames of videos taken with this setup are shown in Figure 2.

A. Camera Settings

The camera hardware allows many settings with the most important ones in this case being: frame rate, exposure time, ISO, saturation and brightness. In Figure 2 different combinations of settings are shown. The frame rate was set to the maximum possible value of 30 fps at a resolution



(a) sat=65, bright=65 (b) sat=65, bright=65 (c) sat=50, bright=55

(d) sat=60, bright=50 (e) sat=75, bright=60 (f) sat=50, bright=50 (g) sat=0, bright=50

Fig. 2. All images are individual frames from different videos captured with a resolution of 1920x1080 at 30 fps and with different camera setups. The two main properties saturation='sat' (default=0, from -100 to 100) and brightness='bright' (default=50, from 0 to 100) are listed beneath each image. (a) shows the full view of the camera. This is what the camera actually films. Figures (b) to (g) are zoomed results with manually marked mites. (b) is the same frame as (a) only zoomed.

of 1920x1080 pixels. The results in Figure 2 use an ISO value of 100 and an exposure time of around $33ms$. The subjectively best configuration was found at a saturation value of 75 (default=0, from -100 to 100) and a brightness of 55-60 (default=50, from 0 to 100). The increased saturation is especially important to emphasize the color difference between mite and bee.

A problem was motion blur. An example is shown in Figure 2g. An exposure time of around $33ms$ yields the risk of motion blur. To reduce motion blur, the exposure time needs to be lowered. This leads to darker images since there is less light permitted to the sensor. To compensate the ISO parameter can be raised or the cameras post processing options brightness and saturation can be adjusted. Raising the ISO or brightness leads to noisier images, which results in a trade-off between image brightness and image quality.

Different settings were tested showing that motion blur can be minimized to an acceptable level at a maximum exposure time of $5ms$ and below. Compared to the previously chosen $33ms$ this results in sufficiently darker images. The difference between mites and bees was emphasised best with the following two settings: *setting A*: ISO=100, $exposure$=5ms, $brightness$=55, $saturation$=70 and *setting B*: ISO=200, $exposure$=3.5ms, $brightness$=50, $saturation$=70. At ISO values greater than 200 too much noise is induced making detection of mites almost impossible.

Another approach is to use sequential images instead of continuous videos. The shortest time for a bee to pass the $4cm$ long sub-tunnel is 1.04 seconds. To make sure that a bee is not missed when taking images instead of videos, the frequency for taking pictures should be smaller than those 1.04 seconds. When taking images instead of videos different internal processing is used, which results in slightly better image quality. Again two settings were found to be optimal: *setting C*: ISO=100, $exposure$=5ms, $brightness$=50, $saturation$=55 and *setting D*: ISO=100, $exposure$=3.5ms, $brightness$=55, $saturation$=55. A comparison of the four settings is shown in Figure 3. Setting B and D have less noise but longer exposure times. Settings A and C have shorter exposure times and more noise.

A minimal setup with only 16 white LEDs (with $5lm$ each) on each end of the tunnel produced almost equal results to a setup with 86 white LEDs ($5lm$ each) on each side. Energy efficiency is important at later stages of the project, because it increases mobility. So a minimalistic setup is to be preferred.

B. Identified Challenges of V. destructor Detection and Potential Solutions

In Figure 2b to 2g different cases are depicted. In Figure 2b two mites are visible on the back. This would be one of the best cases for automatic detection. Mites are clearly visible and the color difference is prominent. Figure 2e shows a hard case for detection. Mites are easily hidden by wings or other parts of the bee. Also mites can be spotted all over the bee, even on its underside, as shown in Figure 2c and 2f.

A great challenge is motion blur. The frames used for Figure 2 were selected by hand. Most other frames were distorted by motion blur, like Figure 2g.

A characteristic feature to be used is the color of the mite. The female *V. destructor* mite - which is the one found on

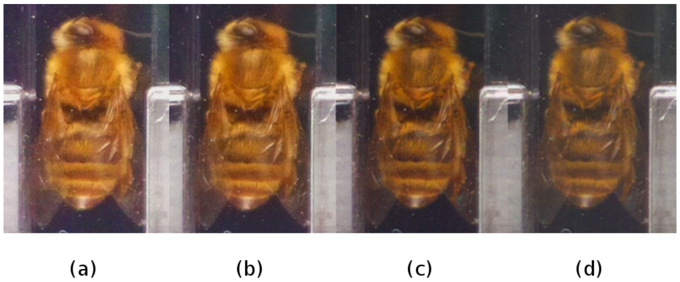


Fig. 3. Detailed comparison of the four settings describet in Section IV. For video analysis: (a) setting A, (b) setting B. For image analysis: (c) setting C and (d) setting D.

bees - has a reddish to brown color which is unusual to honey bees. One could train a classifier based on color, as done in [10]–[12].

Another possible feature is *texture*. Honey bees are known for their typical regular stripe patterns. To classify textures *local binary patterns (LBP)* can be used [13]. Mites are interrupting the regular patterns which could be used for classification [14].

Another approach would be to let the classificator choose the important features by itself. This could be achieved using *convolutional neural networks (CNN)* [15]. This way features like color or edge filters are automatically weighted and learned. Problems are the high amount of necessary training data to tackle the variability within the test data and the high computational costs [15].

V. Conclusion

In this paper a camera system for monitoring honey bees was presented. The goal was to create high quality videos for detecting *V. destructor* mites on bees while they are entering or leaving the hive. A prototype was designed and presented and video results were analyzed. It is shown that with the given hardware it will be a challenging task to fully automatically detect mites on moving bees. Also mites that are partly concluded, for instance by the wings of a bee, are going to be hard to detect. But the setup has proven to get working results and will be deployed on different bee hives to generate data for further analysis.

For future work, different hardware should be tested, supporting a higher temporal resolution of about 50-60 fps. This would eliminate motion blur while keeping the image quality high.

Also different light frequencies aside the visible lights frequencies could be tested. IR ($\geq 550nm$) and UV ($\leq 400nm$) could be used to emphasize features specific to varroa mites, which are less visible. It is also suggested by [9] that bees are less disturbed when using IR light, since they have limited viewing capabilities in this spectrum.

Finally it would be interesting to analyze fluorescence properties of *V. destructor*. It is possible that they emit fluorescence light in a specific wave length when illuminated by fluorescent LEDs.

If the detection of Varroa mites works in real-time, one could extend the system to take automatic actions when a mite is detected. Ideas would be to equip each tunnel with a compressed air gun, that could trigger an air impulse which catapults the bee outside not letting it into the hive. This could also possibly strip off mites from their hosts. Temperature, chemicals or other conditions mites are sensible to could be used to actively control the population inside the hive. Nevertheless, if detection would not be that fast but reliable instead, it would still be of a great benefit, since manual monitoring is expensive.

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