

**EPFL**



---

# RESEARCH INTERNSHIP REPORT

ON BUILDING A 'SMART' MONITORING SYSTEM FOR BEE  
COLONY OBSERVATION

SUPERVISED BY

Prof. Francesco MONDADA  
Dr. Robert M. MILLS  
Mr. Cyril F. MONETTE

MOBOTS LABORATORY - ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

---

Nicolas I. D. ROBSON

September 21, 2023

## ACKNOWLEDGEMENTS

The author would like to extend their gratitude to Sir Lord I. LAIDLAW and the Laidlaw Foundation, to Prof. F. MONDADA and team from MOBOTS laboratory, and to Ms. D.T. NGUYEN and team from the École Polytechnique Fédérale de Lausanne (EPFL) for granting the opportunity of such projects and the corresponding generous fundings.

Furthermore, a special note of sympathy is addressed to his supervisors Mr. C. MONETTE, Dr. R. MILLS and laboratory staff members including Messrs. R. CHERFAN, R. BARMAK and D. BURNIER for the precious advice and knowledge sharing the author has received throughout the eight week internship.

## DISCLAIMER

This report is the formal, detailed explanation to N. ROBSON's Laidlaw Research Poster "Building a 'smart' monitoring system for bee colony observation". This poster can be found on the author's Laidlaw Scholars' Network profile. Please consider reading it first for a better overview of the project's content.

In case of comments, remarks, inaccuracies or claims despite the author's best efforts and proofreading, please contact directly via the following e-mail address.

## AUTHOR'S CONTACT

Nicolas I. D. ROBSON  
Email: nicolas.robson@epfl.ch  
EPFL - Switzerland

# Building a ‘smart’ monitoring system for bee colony observation

Nicolas I. D. ROBSON

2nd Year Bachelor student, Microengineering

## Abstract

Honeybees (*Apis mellifera L.*), of crucial importance for both ecological balance and human economy [2][4], face very high mortality rates causing great concerns [2]. Despite their key significance in pollination including of plants and crops, limited understanding exists regarding their intra-hive collective behaviour.

This research work, undertaken at the MOBOTS laboratory (EPFL), aims to develop new tools to deepen our understanding of honeybee collective patterns [1] and investigate potential mitigation to bee colony decline.

The primary objective of the author’s internship has been co-designing and constructing a monitoring system for an observation hive, containing a honeybee colony. The system had to meet the usability, efficiency, and reliability standards to enable intra-hive study, while addressing the bees’ specific biological and environmental constraints. The project emphasized the implementation of mechanical and electronic monitoring elements required for reliable in-depth behavioural study.

## 1 INTRODUCTION

Honeybees (*Apis mellifera L.*) are famous for their significant role in pollination, with both environmental and economic relevance. Indeed, 35% of worldwide food-crop volume intended to human consumption depend on pollination [4], thus leading to various estimates of the economic significance of animal pollination reaching 153 billion EUR per year worldwide [2] and 1.6-5.7 billion USD per year in the US from honeybees alone [7], far beyond the scale of honey and other bee-derived products sector.

Therefore, the high mortality rates of domestic bee colonies, notably manifested through the Colony Collapse Disaster syndrome, are of great concern for multiple sectors and the global economy [2]. Hence, the drive to develop new tools and techniques to study and acquire knowledge about intra-hive collective behaviour and gain a better understanding of potential mitigation solutions.

In EPFL’s MOBOTS lab, robotics and biology bridge together for the development of such tools, as part of the European HIVEOPOLIS program. To conduct the mentioned study work, designing and implementing an experimental hive observation system with suitable electronic monitoring and mechanical aspects is required. Indeed, honeybees show great sensitivity to their environment, with sources of disturbances including heat [5] [6] and light [3]. These biological constraints, in addition to potential unfavourable local experimental environment metrics and use-purpose constraints, are key criteria to be met. They represent the challenge the author has attempted to address under the supervision of the laboratory team during an eight-week internship.

Through this work, the author aspired to contribute to the understanding of anthropogenic and environmental effects on honeybee populations, with the aim of promoting their conservation and sustainable pollinator management at the societal level.

## 2 METHODOLOGY

The study effort relies notably on sensor and video data acquired from monitoring an observatory hive, hosting a small colony (1000-8000 bees). Miniature computers (Raspberry Pi) and infrared cameras are used as primary footage acquisition, whereas microcontroller-managed sensors measure environmental metrics like temperature, humidity, and organic gas saturation levels in the air.

Therefore, the design and implementation of a monitoring system had three principal axes. First, is the conception of the system’s setup and its mechanical 3D-printed parts allowing precise camera framing and luminosity tuning from the user. Secondly, came the relevance of developing software providing detailed feedback, such as image quality and errors in camera-to-frame alignment, to the user for more precise and repeatable framing of the bee combs and clusters (increase footage quality). The final axis consisted of designing and implementing the hive’s electronic circuits, from power supply, and sensor data acquisition to emergency handling and online data logging (making data and monitoring available remotely to scientists). Furthermore, the monitoring system’s setup has had to satisfy biological constraints inherent to bee studying without risking altering their intra-hive behaviour. Sources of disturbances include sensitivity to light [3] and heat [5] [6]. These were met through the use of infrared lighting (700 to 970 nm), and a modular design of the experimental hive based on a metallic rig structure wrapped with insulation, enabling quality insulation both thermally and acoustically. All the mentioned factors, combined with the use of non-natural materials, have led to the need for close monitoring of the inside-hive environmental conditions (further mentioned in section 2.3).

### 2.1 Mechanical conception work

Filming the bees is intricate. Indeed, bee clusters (‘aggregated bees’) may happen anywhere within the hive and therefore require (1) tunability in framing and camera placement. Furthermore, the computer (Raspberry Pi) running each camera (2) can get to produce significant heat and (3) requires a secured placement within the hive. This has driven the need for an application-specific Raspberry Pi case design with a three Degrees of Freedom (DoF) in-built camera holder, the like of a ball joint (figure 1).

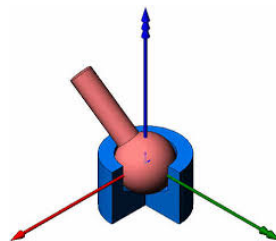


Figure 1: A ball joint allows rotation around the three shown axes. Via ekladata.com

Constraints such as ease of production, reliability, and potential bee toxicity have established the preferred production method of 3D printing from food-safe PLA monofilament. This was achieved through Computer Assisted Design software AutoDesk FUSION 360 and Prusa Slicer.

## 2.2 Computer vision camera aligning script

Having great tunability in camera positioning comes with a set of downsides requiring addressing. The study footage must be repeatable in framing as possible, to monitor bee movement and changes in position over time. Hence the need for a camera-aligning script. This is achieved with the use of four ArUco markers (figure 2) delimiting the Region of Interest (RoI) of the cameras, similar to anchor points of known positions used to reference a boat’s position at sea. The main conception steps were (1) being able to detect the marker position and read its encoded value (‘ID’), (2) providing detailed feedback to the user in a comprehensible and logical sequence, and (3) making the script scalable to more markers and different computer powers (refresh rate).

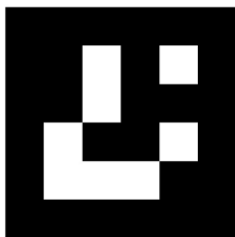


Figure 2: ArUco markers of size 4x4\_50 with encoded value four.

## 2.3 Electronics in the hive

Using low-power card-size computers for footage acquisition has numerous advantages, including low electrical consumption and reduced heating. They are also cheaper and more modular compared to other alternatives. On the other hand, these are usually not best suited for heavy-duty computations, nor sensor monitoring and other hardware interfacing tasks, and are generally less resilient to disruption such as current shortages. This led to a greater architecture planning of the electronics system (figure 3) to enable accurate sensing and environment monitoring, resilience in emergency handling, lower intra-hive heating yet remote accessibility, and high computation power for on-spot data processing (reducing transfers and their size).

To monitor the environmental conditions both inside and outside the system’s module and take action from them, the proposed solution makes use of a microcontroller (MCU, tiny computer with limited functionalities) with a wide array of sensors. These must cover as many known causes of disturbances for bees, to compare the study footage with these metrics and help indicate an abnormal behavior or response from the bees.

Therefore, two identical sensing ‘units’ are proposed. Each would have its own I2C ‘data bus’ of the MCU, ensuring an independent and scalable datapath (in case more sensors are added). Each unit is comprised of (1) multiple temperature and humidity sensors (for higher accuracy and gradient detecting), (2) a CO2 sensor (indicating the activity and ventilation effort of the bees), (3) a UV light (human-invisible) sensor for general-purpose weather recording (outside unit), or overall light disturbance and hive integrity checking (inside-hive unit), (4) VOC (Volatile Organic Compound) and “air quality” gas sensors. Indeed, studies have shown levels of specific types of gas inside a beehive to be correlated with infectious diseases and could be used as a means of detection (Varroosis, [8]).

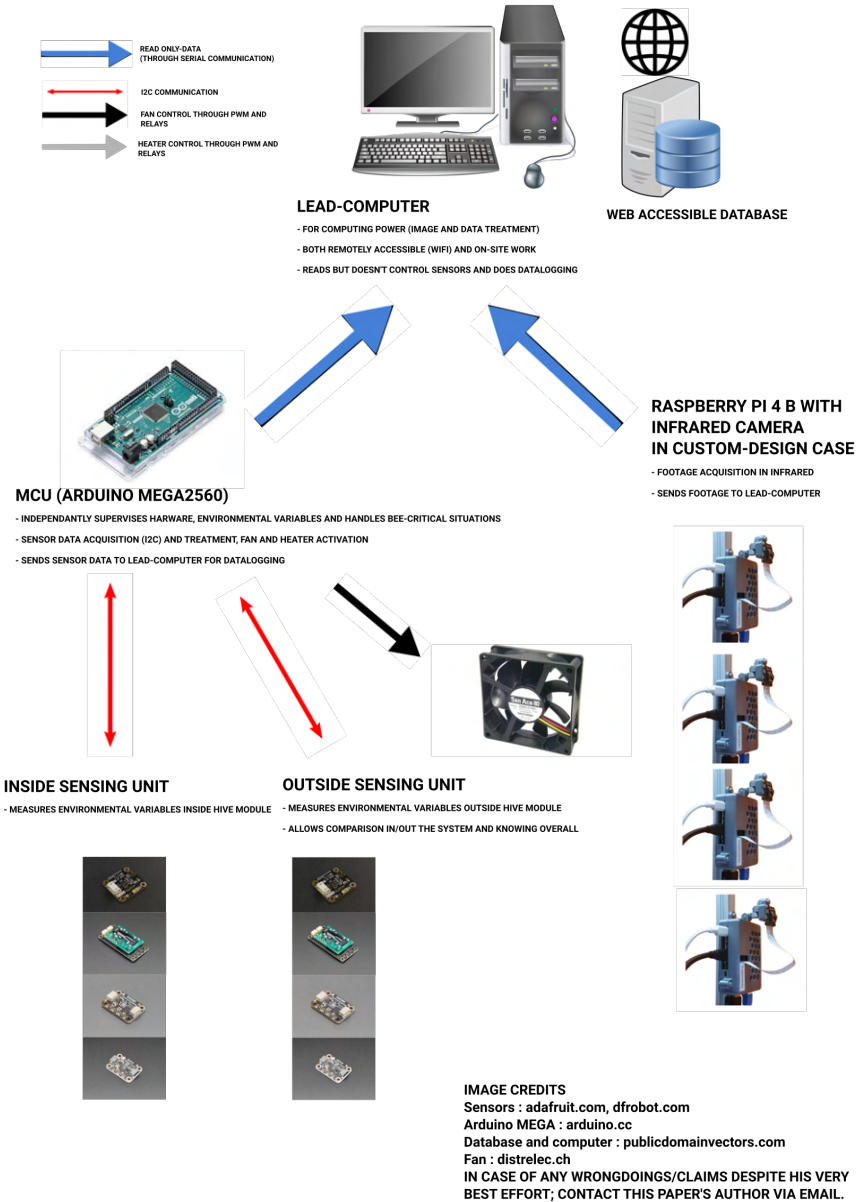


Figure 3: Overall proposed electronic monitoring system, as described above.

Data from the mentioned sensors have three main roles : (1) to signal a dangerous situation (emergency such as an inappropriate temperature within the hive module) leading to triggering a response (fanning or heating, human assistance request, etc.), (2) to assess general quality of the environment for the bees and (3) to serve as a clue, an index, for further investigation of observed phenomena and help remark trends. To do so, the data must be recorded, then made readable and stored remotely (through data logging on an online database).

### 3 RESULTS AND CONCLUSION

#### 3.1 Mechanical conception work

The extensive use of 3D printing throughout the internship has shown it to be a cheap and effective way to produce mechanical components for the monitoring system without significant compromise on performance (figure 4). The parts made following this method were combined with screw-inserts, washers, and other inexpensive metallic parts to compensate for the high rugosity and resulting rough surface of parts otherwise leading to mediocre mechanical properties. Multiple versions of the camera and Raspberry Pi holders were designed and trialed before a model was approved (figure 6). It successfully allowed secure and adjustable placing within the hive module's frame, a three DoF camera tuning, and robustness to mechanical shock and wear. Similarly, an LED strip holder has been designed and delivered to the supervisors, allowing them to precisely orient the light on the desired Region of Interest.

Furthermore, the modularisation of the hive's monitoring system within a metallic frame (figure 5) proved to be a strong and scalable approach for mounting, transportation, and overall ease of use. Both camera and lighting positions can be finely tuned by researchers as a result of this internship.

As a future enhancement, the electronic components such as sensors used in the hive could be attached to the metallic frame similarly to the cameras, using 3D printed holders and pads to be developed. This would ensure secure and adjustable placing of the sensors, notably to measure temperature gradient within the system.

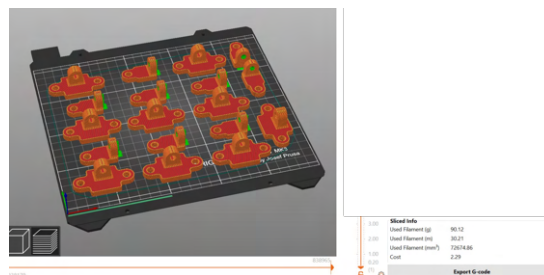


Figure 4: Ease of LED holders production using 3D printing tools.

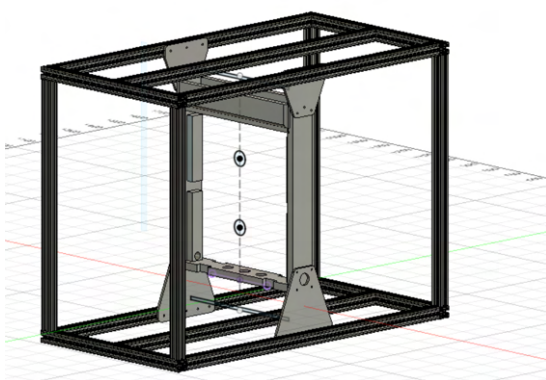


Figure 5: CAD model of the monitoring module's frame.



Figure 6: Camera and Raspberry Pi case (yaw, pitch and roll angles are adjustable).

### 3.2 Computer vision camera aligning script

This experience has attested to the relevance of computer-vision tools (markers etc.) in experimental device-tuning and otherwise general study of moving elements. Indeed, paired with the need for camera position adjusting, came the urge to define and standardize the image framing to increase footage quality. The approach using ArUco markers was shown to be resilient to lighting conditions, varied marker sizes, and rather inhomogeneous image backgrounds, thereby displaying extreme reliability in ArUco detection in all test cases.

Although challenging to provide placement instructions solely using the camera's footage, the script showed to be reliable on a Raspberry Pi and effectively allows the user to tune the camera to a predefined setting along five degrees of freedom (figure 7). An amelioration lead would be to further test the correction metrics suggested by the script's user feedback, and simplify the procedure to increase aligning speed.

Furthermore, one could easily imagine a system in which each bee has its marker, allowing precise individual movement recording and analysis (position, speed, activity), for the meagre requirements of a high-quality camera and a dedicated Python script based on the author's work.

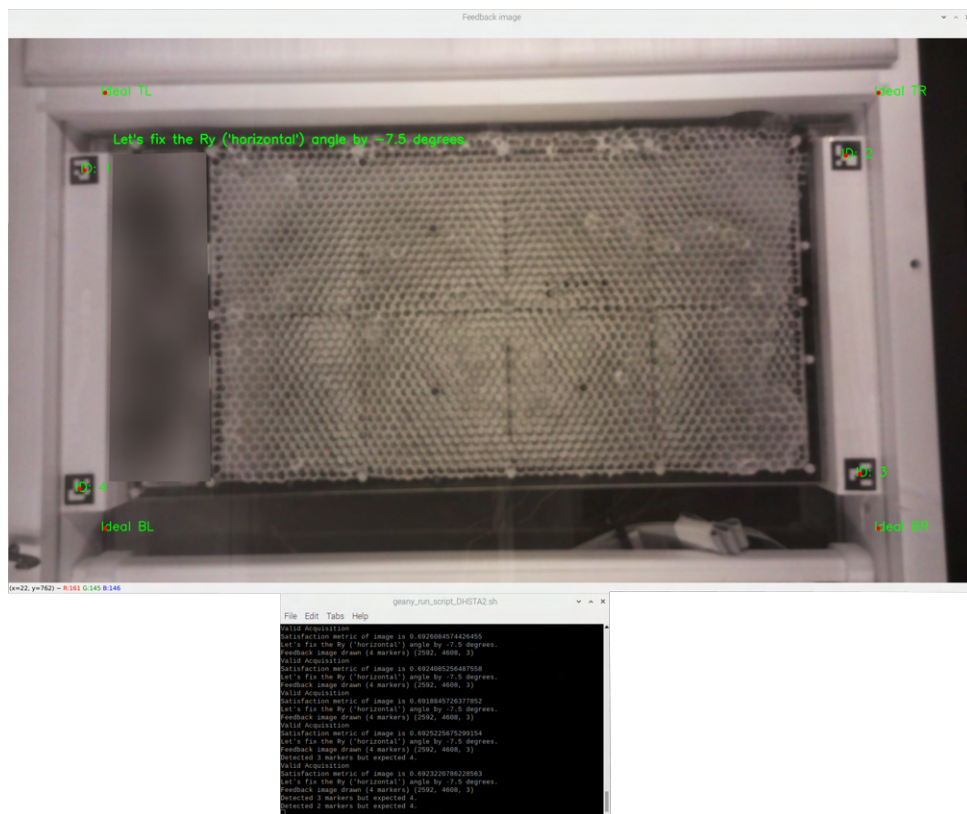


Figure 7: Adjusting the camera framing using the aligning script.

Top: Honeycomb in observatory hive with ArUco markers, that have been detected. In green and Bottom: Feedback is provided to the user in order to improve framing.

### 3.3 Electronics in the hive

The proposed prototype version showed success in sensor reading, acting on the values (ventilation control), and data logging to remotely accessible (cloud-based) data analysis tools (figure 8). All the hardware components were fetched, and basic functionalities have been approved for higher-level use (modular approach). The task involved designing and binocular soldering of a multi-transistors-based PWM relay for the precise control of the fan (on, off, speed) (figure 9).

For scalability and clarity purposes, a precise array structure was defined to standardize the data format. This allowed to extend the number and types of sensors used on each line, while maintaining clear and uniform readability to process information. This approach further enables the detection of any individual sensor malfunctioning. Data from each sensor would be communicated by the MCU (here an Arduino device) to the lead computer in the following format:

```
[Sensor Type,Inside/Outside,Sensor ID,{data1,data2,...}]; .
```

Improving the current version proposed to the laboratory would be to test the electronic system at full scale, with the following steps : (1) fully implementing a sensing unit and reading the data from the cloud (small web-connected weather station), (2) implement the two-sensing-units system (monitoring inside/outside the structure) with automated data logging, (3) define and implement trigger conditions for emergency responses, and (4) securely attach components to the hive module's frame using 3D printed pads and holders.

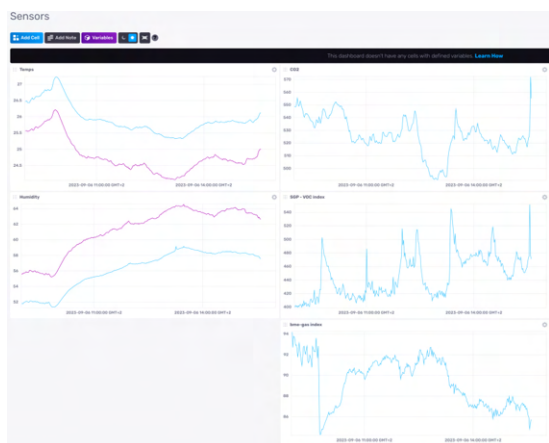


Figure 8: Web-accessible data plots for each metric, from the sensing unit prototype.

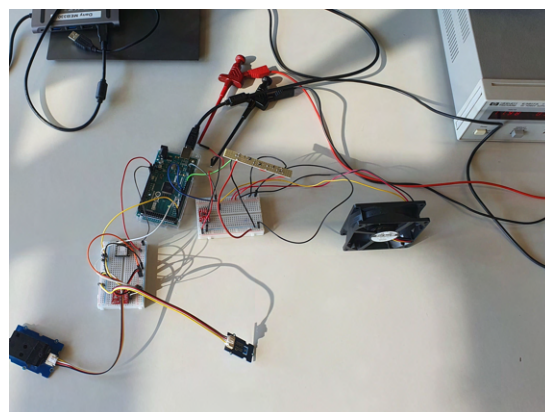


Figure 9: Functioning sensing unit prototype, performing sensor reading and fan control.

## 4 GENERAL CONCLUSION

This research internship has contributed to the conception and implementation of a monitoring system for bee colony observation, thereby to a new fundamental study tool for varied bee-centered research initiatives. It has been an incredible occasion to learn and apply practical concepts from mechanical, software, and electrical engineering fields while living a unique human experience. The author gained practical skills and motivation to pursue his interests in robotics, through a truly passionating internship resulting in concretely implemented tools for École Polytechnique Fédérale de Lausanne's MOBOTS laboratory.

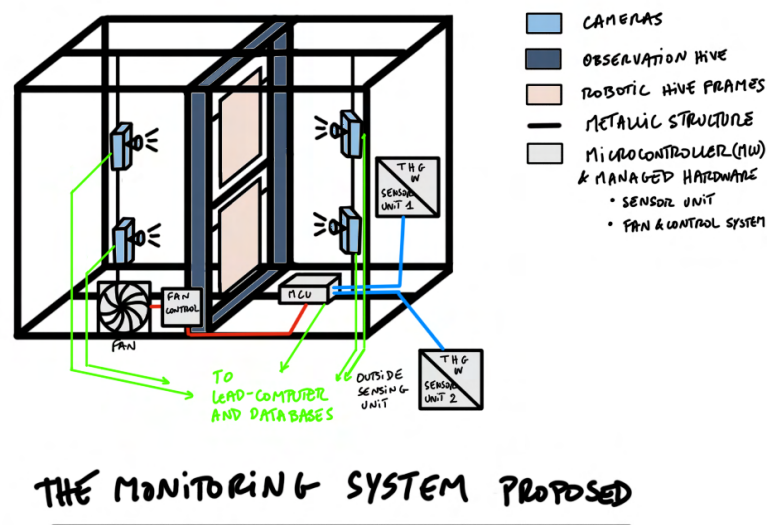


Figure 10: An artistic sketch view of the monitoring system as built during the internship.

## References

- [1] Rafael BARMAK, Martin STEFANEC, Daniel N. HOFSTADLER, and et al. A robotic honeycomb for interaction with a honeybee colony. *Science Robotics*, 8(76):eadd7385, 2023.
- [2] Nicola GALLAI, Jean-Michel SALLES, Josef SETTELE, and et al. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological economics*, 68(3):810–821, 2009.
- [3] N. HEMPEL DE IBARRA, Misha VOROBYEV, and Randolf MENZEL. Mechanisms, functions and ecology of colour vision in the honeybee. *Journal of Comparative Physiology A*, 200:411–433, 2014.
- [4] Alexandra-Maria KLEIN, Bernard E. VAISSIÈRE, James H. CANE, and et al. Importance of pollinators in changing landscapes for world crops. *Proceedings of the royal society B: biological sciences*, 274(1608):303–313, 2007.
- [5] Fredi KRONENBERG and H. Craig HELLER. Colonial thermoregulation in honey bees (*apis mellifera*). *Journal of comparative physiology*, 148:65–76, 1982.
- [6] James SIMPSON. Nest climate regulation in honey bee colonies: Honey bees control their domestic environment by methods based on their habit of clustering together. *Science*, 133(3461):1327–1333, 1961.
- [7] E. E. SOUTHWICK and L. SOUTHWICK Jr. Estimating the economic value of honey bees (hymenoptera: Apidae) as agricultural pollinators in the united states. *Journal of Economic Entomology*, 85(3):621–633, 1992.
- [8] Andrzej SZCZUREK, Monika MACIEJEWSKA, Beata BAK, and et al. Gas sensor array and classifiers as a means of varroosis detection. *Sensors*, 20(1):117, 2019.