SAMS

Smart Apiculture Management Services

International Partnership on Innovation

SAMS - Smart Apiculture Management Services

Deliverable N°3.4

Evaluation of HIVE Prototype Designs

Work package N° 3 – HIVE System

Horizon 2020 (H2020-ICT-39-2017)

Project N°780755

german cooperation
DEUTSCHE ZUSAMMENARBEIT

This project has received funding from the European Union´s Horizon 2020 research and innovation programme under **grant agreement N° 780755.** The sole responsibility for the content of this document lies with the authors. It does not necessarily reflect the opinion of the EU.

Project information		
Lead partner for the deliverable	University of Kassel, Faculty of Organic Agricultural Sciences, Agricultural and Biosystems Engineering. Head of Department and Project lead: Prof. Dr. Oliver Hensel	
Document type	Deliverable	
Dissemination level	Public	
Due date and status of the deliverable	Due date: 31.08.20	Submitted 31.08.20
Author(s)	Sascha Fiedler, Dr. Sascha Kirchner	
Reviewer(s)	GIZ	

This document is issued by the consortium formed for the implementation of the SAMS project under Grant Agreement N° 780755.

SAMS consortium partners

Logo	Partner name	Short	Country
	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH (Coordinator)	GIZ	Germany
	University of Kassel	UNIKAS	Germany
	University of Graz (Institute for Biology)	UNIGRA	Austria
	Latvia University of Life Sciences and Technologies	UNILV	Latvia
	ICEADDIS – IT-Consultancy PLC	ICEADDIS	Ethiopia
	Oromia Agricultural Research Institute, Holeta Bee Research Center	HOLETA	Ethiopia
	University Padjadjaran	UNPAD	Indonesia
	Commanditaire Vennootschap (CV.) Primary Indonesia	CV.PI	Indonesia

List of Abbreviations

A/D	Analog/ digital
AC	Alternating current
ADC	Analog Digital Converter
ARM	Advanced RISC Machine
DAT	Data
DC	Direct current
DSS	Decision Support System
DW	Data Warehouse
ET	Ethiopia
FFT	Fast Fourier Transformed
GND	Ground
GPIO	General-purpose input/output
GSM	Global System for Mobile Communication
HI-FI	High fidelity
ICT	Information and Communication Technology
IDN	Indonesia
IP	Internet Protocol
LAN	Local area network
LED	Light-emitting diode
MU	Monitoring unit
PCB	Printed Circuit Board
PWM	Pulse Width Modulation
RAM	Random-access memory
SD	Secure Digital
SMS	Short message service
SDG	Sustainable Development Goals
SPL	Sound pressure level
VCC	Common Collector Voltage
VGA	Video Graphics Array

Summary of the project

SAMS is a service offer for beekeepers that allows active monitoring and remote sensing of bee colonies by an appropriate and adapted ICT solution. This system supports the beekeeper in ensuring bee health and bee productivity, since bees play a key role in the preservation of our ecosystem, the global fight against hunger and in ensuring our existence. The high potentials to foster sustainable development in different sectors of the partner regions are they are often used inefficient.

<u>Three continents - three scenarios</u>

(1) In Europe, consumption and trading of honey products are increasing whereas the production is stagnating. Beside honey production, pollination services are less developed. Nevertheless, within the EU 35% of human food consumption depend directly or indirectly on pollination activities.

(2) In Ethiopia, beekeepers have a limited access to modern beehive equipment and bee management systems. Due to these constraints, the apicultural sector is far behind his potential.

(3) The apiculture sector in Indonesia is developing slowly and beekeeping is not a priority in the governmental program. These aspects lead to a low beekeeper rate, a low rate of professional processing of bee products, support and marketing and a lack of professional interconnection with bee products processing companies.

Based on the User Centered Design the core activities of SAMS include the development of marketable SAMS Business Services, the adaption of a hive monitoring system for local needs and usability as well as the adaption of a Decision Support System (DSS) based on an open source system. As a key factor of success SAMS uses a multi stakeholder approach on an international and national level to foster the involvement and active participation of beekeepers and all relevant stakeholders along the whole value chain of bees.

The aim of SAMS is to:

- enhance international cooperation of ICT and sustainable agriculture between EU and developing countries in pursuit of the EU commitment to the UN Sustainable Development Goal (SDG N°2) “End hunger, achieve food security and improved nutrition and promote sustainable agriculture”
- increases production of bee products
- creates jobs (particularly youths/ women)
- triggers investments and establishes knowledge exchange through networks

Project objectives

The overall objective of SAMS is to strengthen international cooperation of the EU with developing countries in ICT, concentrating on the field of sustainable agriculture as a vehicle for rural areas. The SAMS Project aims to develop and refine an open source remote sensing technology and user interaction interface to support small-hold beekeepers in managing and monitoring the health and productivity in their own bee colonies. Highlighted will be especially the production of bee products and the strengthening of resilience to environmental factors.

- Specific objectives to achieve the aim:
- Addressing requirements of communities and stakeholder
- Adapted monitoring and support technology
- Bee related partnership and cooperation
- International and interregional knowledge and technology transfer
- Training and behavioral response
- Implementation SAMS Business cooperation

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Executive summary

In cooperation with the project partners and based on a User Centered Design process, the bee monitoring system SAMS HIVE was developed at the University of Kassel and elaborated to a marketable product. The HIVE system collects data from the bee colony and includes remote data transmission and evaluation of stability and quality. The system is suitable for stationary and migratory beekeeping due to its modularity and possible pre-configuration. The systems have been tested under real conditions for several months. Implementation workshops were also held in the target countries Indonesia and Ethiopia, and components for 50 HIVE systems each were provided and partly implemented. An adaptation to the individual needs of the beekeepers is possible. For example, the sensors for weight, temperature, humidity and acoustics can be used individually and extended if necessary. Measuring intervals and settings can be configured online remotely. Findings were also regularly shared and discussed during product development. During the test phase, detailed protocols were collected by the responsible project members in cooperation with the beekeepers to be used as a basis for data evaluation.

Due to COVID 19 there were also cuts in the planned implementation in this work package, but the project goals were not significantly affected.

1. Introduction

1.1 Design principle

The partner countries Indonesia and Ethiopia are quite divergent in culture and other preconditions. Therefore, a team of local experts have been analyzed requirements in each country. Methods of UCD are suitable to organize effective and efficient collaboration between partners. Based on two phases of user research and on one Workshop for each of the two target regions West – Java and Ethiopia as well as a study on specific beekeepers needs within work package 2, the following key points were identified:

- Bee colony should be free from pests attack (wasps, ants, rats etc)
- Bee colony should be safe from thief
- Beekeeper should get support and coaching
- New technology or methods should boost the productivity
- Bee colony should to be free from any disease
- System should help to take an appropriate action
- System should help to know how much honey is allowed to be harvested in a colony
- Beekeeper should know if the colony is safe enough to be checked or not
- Beekeeper wants to know if there is an upcoming swarm in the colony
- Beekeeper wants to know the strength of the bee colony

Basic hardware requirements based on UCD research:

- Power grid independent, for location-independent installation
- Cost-effective, in order to enable smaller beekeepers to obtain financing as well
- To reproduce with simple means in order to be able to reach a broad target group
- Open source, for easy access and further development in the community
- Expandable by further measurement parameters (e.g. weather station, camera) to cover a wide range of sensor options
- Transferable to common hive sizes, for easy installation
- Wireless data transmission, for rapid availability for the end user and researchers
- Low data volume, for fast and cost-effective data transfer
- High stability, enabling low maintenance and long-lasting data collection
- Sustainability: Components and construction which are modular and easy to recycle

All those key points and requirements built the basis for the selection of hardware components for the SAMS HIVE system and the iterative development steps.

1.2 Design process

According to the DIN ISO 9241-210 for UCD one product, hardware as well as software, has several iterations of the human/user-centered-design development cycles. Thus, the technical specifications and technical requirements were steadily under improvement and adaption to address the local needs and usability:

- Research of sensor options, component configuration and autonomous power supply
- Component selection and construction of various prototypes
- Programming the Single-Board-Computer
- Application test of the energy system
- Application test of the monitoring system
- Evaluation of the prototype for further development
- Definition of further development requirements

In the following the stages of the prototype development are shown and the essential differences are briefly described:

1st prototype (lo-fi):

- Single Board Computer and audio device: Raspberry Pi 3 with Sound module RASP WOLF AUDIO and regular 3.5 mm microphone.
- Case and cables: A regular beehive brood chamber has been used as case.
- Power supply: A photovoltaic system was added on top of every case as a power supply.

- Implementation: 10 systems of the lo-fi prototype have been installed in the acoustic lab as well as at the bee site of UNIKAS to take audio data of swarming events (Fig. 1)

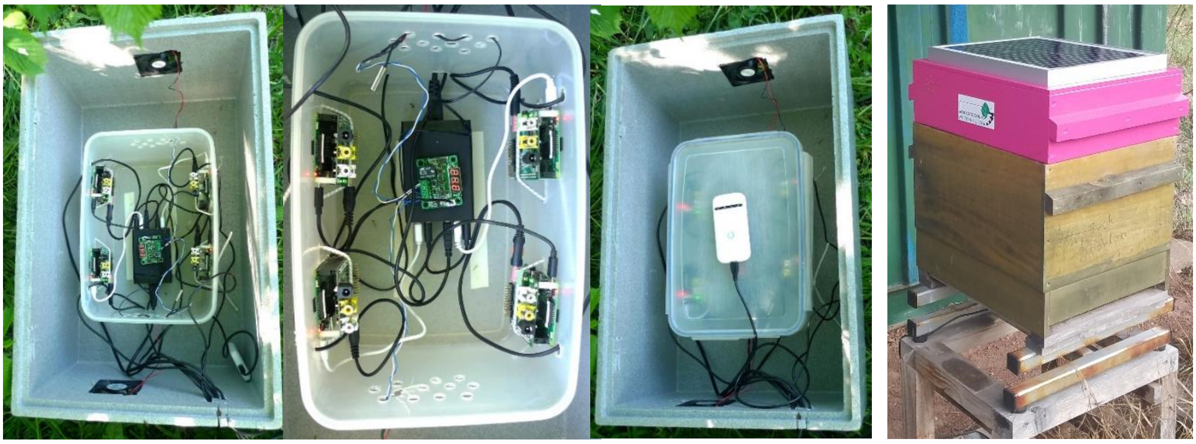


Figure 1: Implementation of lo-fi prototypes at test site UNIKAS

2nd prototype (hi-fi):

- Single Board Computer and audio device: Raspberry Pi Zero W with I2S MEMS microphone.
- Breadboard and PCB: The main components are plugged onto a developer board, a so-called breadboard. This enables various hardware tests and different components to be tested quickly in order to develop a dedicated circuit board (PCB) in the next step.
- Power supply: An external photovoltaic system supplies up to 10 systems with power. As an intermediate step, a control unit with relay board and own time-controlled energy management (Witty Pi) was also used to test a cost-reduced power supply.
- Sensors: All necessary sensors are installed and tested for errors and accuracy. Different positions for the placement of the sensors were evaluated.
- Implementation: 5 Systems of the hi-fi prototype have been installed at beesite of UNIKAS as well as in the partnercountries Indonesia and Ethiopia (Figure 2, 3).

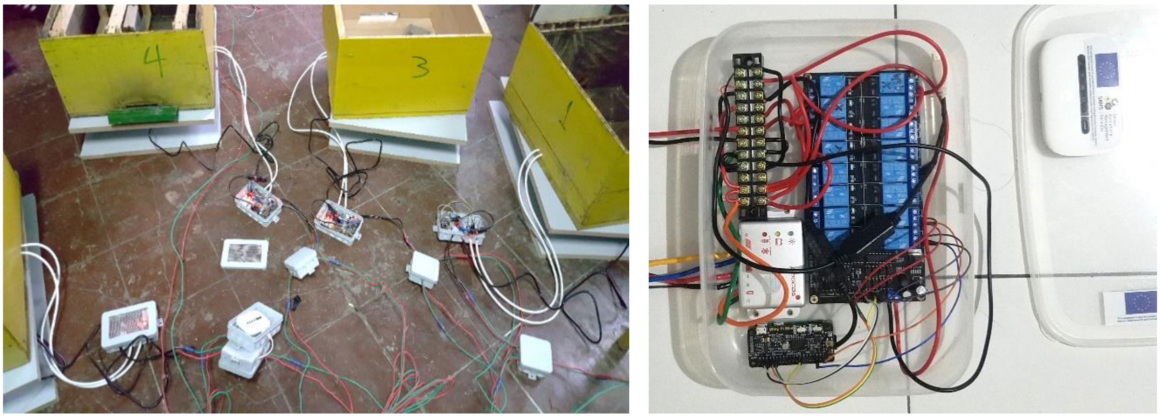


Figure 2: Hi-fi prototypes in Ethiopia (left) and control unit with charging controller (right)

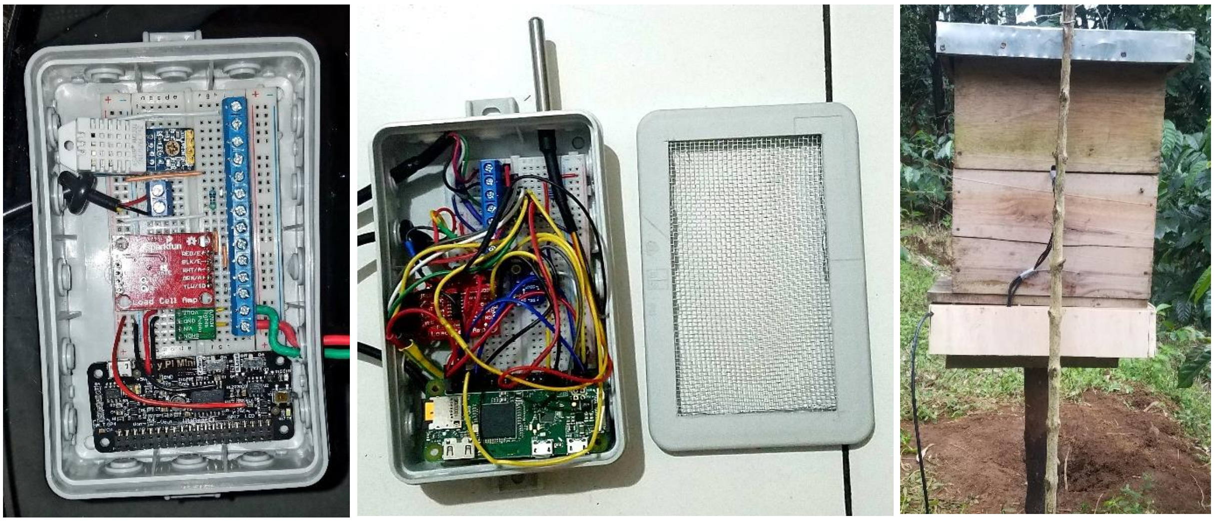


Figure 3: Hi-fi prototypes (left) and beehive with hi-fi prototype (right) in Indonesia

Final HIVE system:

- Software: Several software adaptions to reduce bugs and implement additional features like remote update function and online configuration.
- Case and cables: 3D printable cases for computer and sensors as well as plugs and cables for simple installation (Figure 4, 5).
- Implementation: EU: 15 systems have been installed at UNIKAS and at testsites of partners in Ethiopia and Indonesia, 5 systems are ready to install and will be implemented soon. IDN: 45 systems have been built and partly already installed. Partners are still being looked for to implement the remaining 26 systems. ET: 15 systems are currently implemented. For the remaining 35 systems ICEADDIS and HOLETA are waiting for components which are currently in Ethiopian customs. In addition, 200 bee colonies with beehives will be acquired in Ethiopia and Indonesia for further investigation.

Figure 4:SAMS Sensorcase installed in regular brood frame connected with flatcable to SAMS HIVE system

Figure 5: SAMS HIVE system

1.3 Function principle

Up to 10 monitoring systems are supplied with power by one photovoltaic system. A DC/DC converter regulates the input voltage of the photovoltaic battery to 5V. The monitoring systems are based on a single-board computer Raspberry Pi Zero W with WiFi. The computer can be equipped with an attachable Witty Pi 3 Mini extension to obtain very differentiated switch-on and switch-off cycles. The Witty Pi mini allows the Raspberry Pi to be completely disconnected from the power supply between measurements, thus saving energy. Various sensors can be connected to the RasberryPi. The software is prepared to connect temperature and humidity sensor (DHT22), temperature sensor (DS18B20), microphone for recording the frequency spectrum (SP0645) as well as a load cell (H30A).The components are soldered, plugged and connected to a PCB made for this purpose. The software must be calibrated before the first operation. For this purpose, the user needs to connect to the system using a smartphone via WiFi and perform the calibration through a web browser. A standard mobile GSM Wifi router is used to connect to the Internet. The router can link up to 10 systems and is connected to one of the Raspberry Pis for its power supply.

The measuring intervals and parameters can be changed online in the Data Warehouse. The online configuration is checked by the system before each measurement and changes are updated if necessary. The software is Open Source and located on a githubserver. Software updates are automatically requested after each measurement and installed if necessary. Afterwards the system is shut down automatically, disconnected from the power by Witty Pi and waits for the next predefined start by Witty Pi. The Witty Pi Schedules can also be adjusted online. They are also updated with the online configuration. If no energy saving as well as differentiated measuring intervals are required, the Witty Pi can be omitted and the software starts the next measurement automatically after a certain time. This time setting can also be changed online. All collected data is sent to the Data Warehouse and stored there. Reports can be created and data can be graphically visualized. Log files are also sent to the Data Warehouse. This enables a differentiated error diagnosis. The software also includes automatic error handling for a wide range of error scenarios and is designed to display the status via RGB LED for fast on-site error diagnosis.

In case there is no Internet, the data is stored on the microSD card and can be read out locally through SSH access via WiFi or directly from the SD card with a computer. In case of internet breakdowns, the data will be cached and sent to the data warehouse with the next internet access. All data that has been sent successfully will be automatically deleted from the device to reduce storage space. If the storage space becomes insufficient, the system deletes the data of every second measurement until storage can be released again. To reduce measurement uncertainties, the results of several short series of measurements are taken as an average. If there are strong outlier values between two measurements, the measurement is repeated. The respective parameters can also be set in the online configuration. The sensors are built into sensor frames provided for this purpose and can thus be placed in the bee colony. The connection is made via a cable. The scale is located in a frame under the beehive. The computer with PCB is installed in a waterproof case in the scale framework. Chapter 3.4 describes the software processes in more detail and shows a flow chart for the basic software flow. Behind it, there are several other processes.

1.4 Power supply principle

The photovoltaic system is only used for power supply. Any other power source adapted to the system can be used. DC power sources between 5V and 23V as well as standard AC power sources with micro-USB power supply are suitable. The dimensioning of the power supply is based on the standard measuring interval with the given hardware. It can be extended as needed and is independent of the SAMS HIVE system. Table 1 shows the calculation of the total energy demand. Table 2 shows the values of the Global horizontal irradiation for the partner countries and EU. Figure 6 and Figure 7 show the average irradiation graphically. For the project and as a recommendation the following configuration is used (also see Report 3.3):

A monocrystalline 12 Volt Phaesun Sun Plus 50 S solar module with 50 Wattpeak output was selected as solar module. A 10 Ampere PWM Phocos eco 10 charge controller was installed between the battery and the solar module. A standard car battery (100 Ah) is needed as accumulator. Charge controller and battery needs to be placed in a water-protected box and need to be connected with standard 12 Volt cabels to the solar module and the SAMS HIVE system.

Table 1: Power Consumption per day

Consumer	Amount of Measure ments per Day	Amount of MU	Length of Measure ment [min]	Total Consumption per Day [h]	Power Consumption per Device [mA]	Total Consumption [Ah]
Monitoring Unit (MU)	56	9	5	4,67	70-**200**	8,40
Mobile GSM Router	56	1	10	9,33	400	3,73
					Total	**12,13**

Table 2: Global horizontal iIrradiation per Country/ EU and year in average (globalsolaratlas.info)

Country	Min	Max	Average	Monthly	Daily	Unit
ET	1753	2483	2118	177	6	kWh/m²
IDN	1314	2191	1753	146	5	kWh/m²
EU	803	2118	1461	122	4	kWh/m²
GLOBAL	803	2702	1753	146	5	kWh/m²
GER	951	1257	1104	92	3	kWh/m²

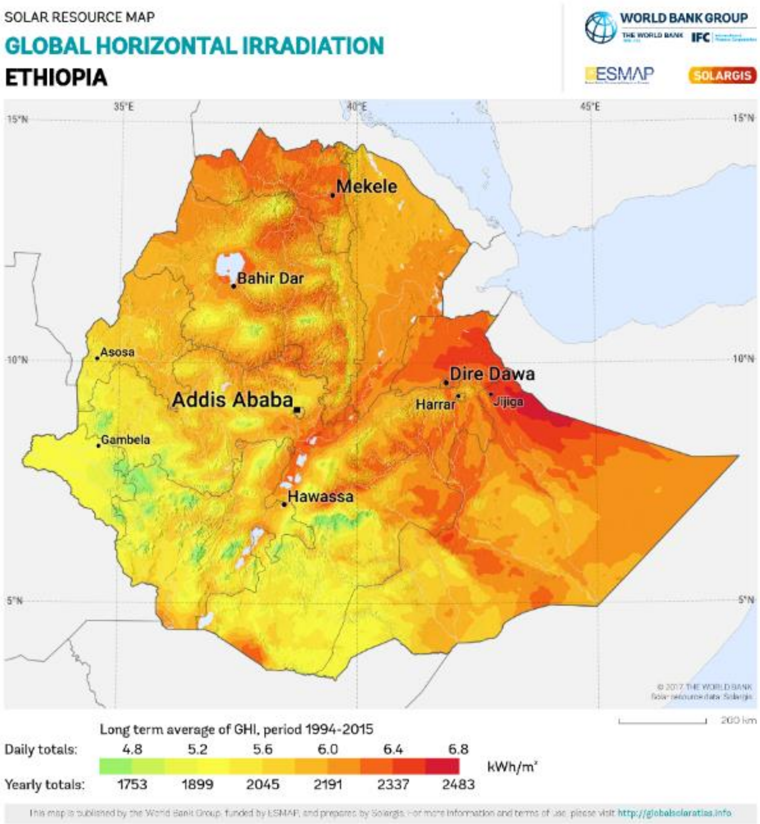


Figure 6: Global horizontal irradiation in Ethiopia (globalsolaratlas.info)

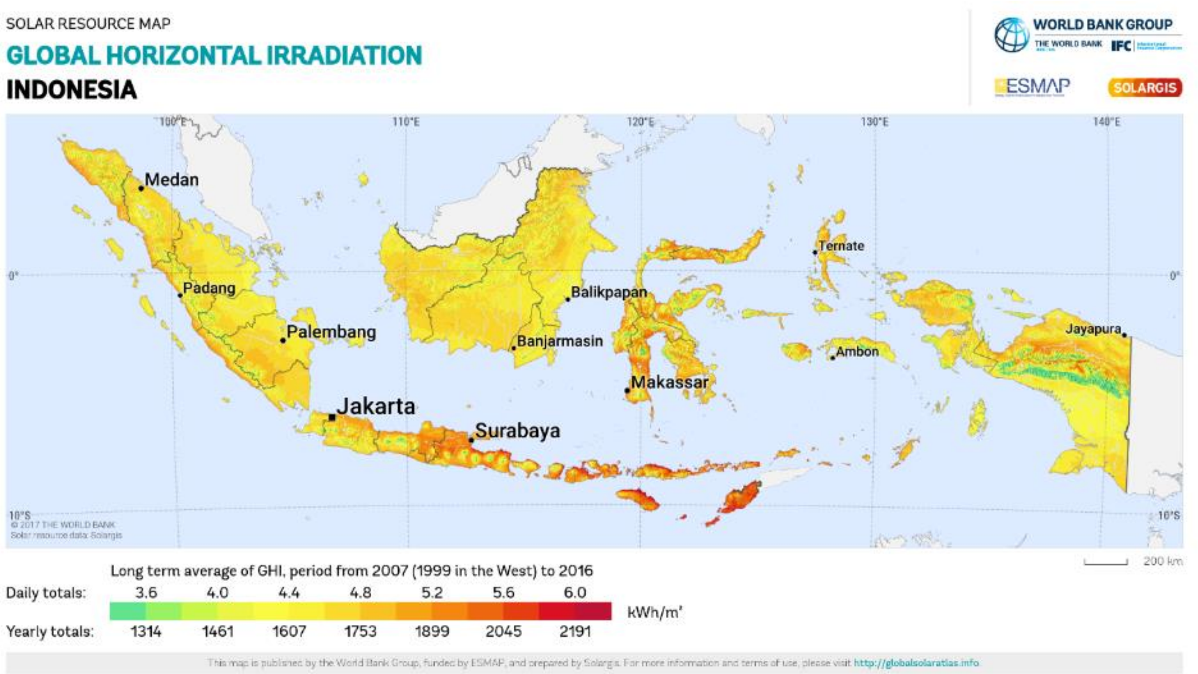


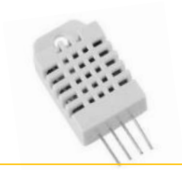
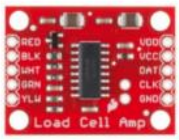
Figure 7: Global horizontal irradiation in Indonesia (globalsolaratlas.info)

2. Hardware

2.1 Components

Table 3 lists the main components of the SAMS HIVE Monitoring System.

Table 3: Components of the HIVE Monitoring System

Component	Function	Specification	Photo
Raspberry Pi zero w	Single board computer	ARM v7 1GHz processor, 512MB RAM, On-board Wireless LAN 2.4Ghz, On-board Bluetooth and micro-SD Card reader	
UUGear Witty Pi 3 mini incl. DS3231SN	Energy manager + Real time clock	Exact time for up to 17 hours	
Dallas DS18B20	Temperature inside hive	Operating range -10°C to +85°C +/- 0.5°C	
Aosong DHT22	Temperature and humidity	Operating range humidity 0-100% +/-2% temperature -40 to +80°C +/- 0.5°C	
Microphon Adafruit I2S MEMS SP0645	Records acoustics inside hive	Operating range 50Hz - 15KHz	
BOSCHE H30A load cell	Weight measurement	Accuracy class C3 and nominal load of 200kg. IP65, as outside hive	
AVIA Semiconductor HX711	A/D converter	24-bit analog-to-digital converter	
Step-down converter mini-360	Connects the device to 12V	Output voltage is adjustable between 5 - 23V	

Data sheets or links for all main components can be found in the appendix. As shown in Chapter 2.6, the costs of the monitoring system are about 170 €. For the placement and connection of the components a PCB was designed (Figure 8).

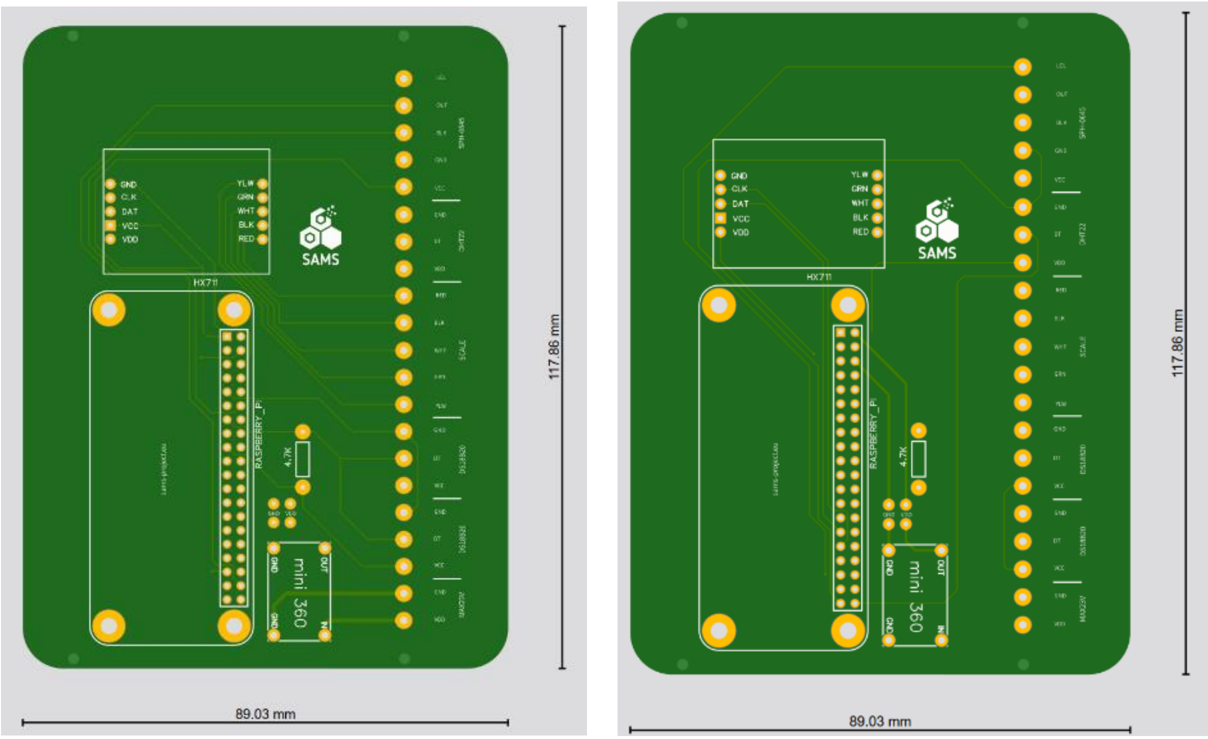


Figure 8: Top and bottom view of a ready to print circuit layout for the SAMS HIVE Monitoring System

2.2 Case and cables

A case was developed for the PCB (Figure 9). It can be produced with standard 3D printers. The SAMS HIVE prototype case was printed with a Zmorph VX with ABS filament. It can be equipped with cable ducts for load cell, connectors for power and flat cable as well as RGB LED for status indication and is easy to install (Figure 10). The connection to the load cell and sensors is via cable. The case is optional and can be replaced by other common cases. For the sensors a separate case was developed (Chapter 2.3). All CAD plans for printing are open source available (Figure 11, Chapter 3.1).

Figure 9: 3D printed SAMS HIVE Case

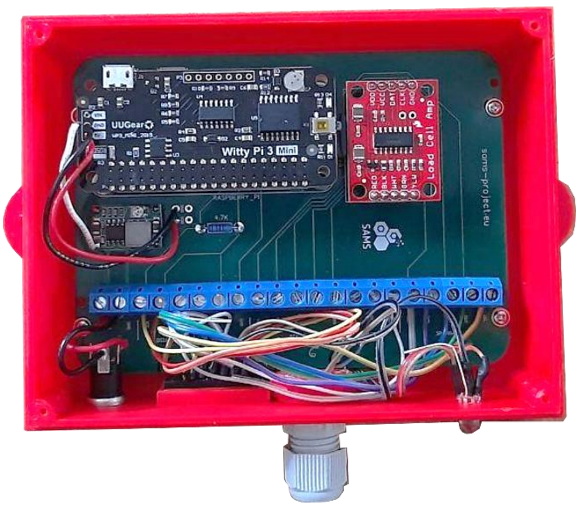


Figure 10: Opened 3D printed SAMS HIVE Case with PCB and components

Figure 11: CAD Sketch of SAMS HIVE Case

2.3 Sensor case and placement

The sensor case provides predefined slots for microphone, humidity and temperature sensor. The sensors are connected to the computer via flat cable with a socket and corresponding IDC connector. It can be opened by sliding closure (Figure 13). A wire mesh is fitted into the top lid. The case is a result of several experiments on different installation positions of the sensors in the bee colony as well as different materials. A wire mesh with 0.2mm mesh width is the least vulnerable material to propolisation of the mesh, therefore it was preferred to the printable plastic mesh (Figure 12) and standard metal fly screens with larger mesh width for the final version of the sensor case. As an installation position, the tests for the inframe position (Figure 12) showed a clear advantage with regard to the accuracy of the measured values and interference from wax and propolis compared to the positions in the honey chamber (see Report 3.2) and the position in the inlay frame between honey chamber and brood chamber (see Deliverable 3.3 hi-fi prototype) of the hive.

Figure 12: Sensor case installed in regular brood frame connected with flat cable

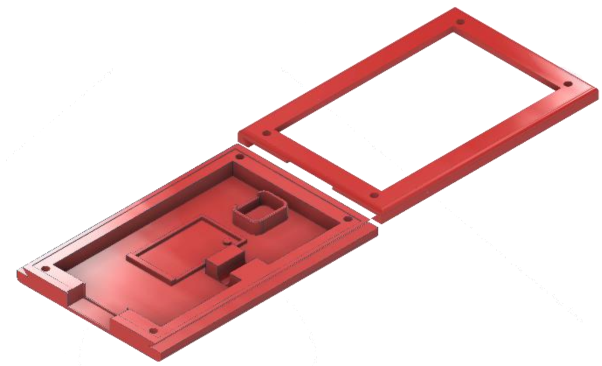


Figure 13: CAD sketch of 3D printable SAMS Sensor case

2.4 Scale unit

Three variants were tested for the placement of the load cell under the beehive: a load cell with aluminium plate and wooden structure on both sides, a load cell with steel frame and in addition, a variant from a comparable project (www.beelogger.de) with two load cells and aluminium profile rails to increase stability (Figure 14). There, the choice of materials is only influenced by the availability of materials, the budget and the requirement for high robustness.

Figure 14: Scale unit with load

2.5 Data transmission

A mobile 2G/3G GSM Wi-Fi router type E5330 from HUAWEI is used to send the data to the Internet. A machine-to-machine approach was tested for another prototype of UNILV and is useful there. For the HIVE system, however, larger amounts of data are sent due to the acoustic data (FFT spectrum), so at least a 3G connection is recommended. Any existing WiFi network can also be used. The data transmission is protected by the auth0 service to the Data Warehouse (DW) developed by UNILV (see Report 4.1). In order to detect errors caused by disturbances of the radio connection, the signal strength can be logged online in the DW regularly. In case of internet breakdown or strong signal interference, the data is stored on the SD card until the next successful upload. The data can also be stored offline and read out from the SD card afterwards.

2.6 Costs

The cost of the components for the production of a SAMS HIVE system comes to about 170 €, as shown in Table 5. Minor costs have been summarized as collective items and may vary slightly in price (Pos. 16, 17). Of course, the costs depend on the usual factors including price development and number of units and represent only an instantaneous value. The costs for WiFi router and photovoltaic system are not included, as these can be shared by up to 10 HIVE systems each or can be based on existing technology and power supply. For a small commercial beekeeper, for example, it would be conceivable to set up only one HIVE system close to the residence (power/ WiFi available), for instance to monitor the nectar flow or the pre-winter-feeding phase. Up to 10 additional bee colonies could be equipped with a temperature sensor, for example to monitor brood activity over the winter and thus optimize varroa tolerance. If the location requires a self-sufficient power supply, the costs for the supply of up to 10 HIVE systems are around 200 € (Table 4). The output can be adjusted individually by selecting other components.

Table 4: Cost calculation for Photovoltaic system

Pos	Name	Decription	Spec		Qty	Price per Item (in Euro)
			Brand	**Type**		
1	Solar module	50Wp Photovoltaic cell	Phaesun	Sun Plus 50	1	90 €
2	Charging control	10A current control	Phocos	eco 10	1	40 €
3	Batterie	Accumulator	Standard car battery	100Ah	1	70 €
					Total	**200 €**

Table 5: Cost calculation for SAMS HIVE System

Pos	Name	Decription	Spec		Qty	Price per Item (in Euro)
			Brand	Type		
1	RasperryPi Zero	Single-Board-Computer	Raspberry Pi Foundation	Zero W	1	13 €
2	WittyPi	Powermanagement	UUGear	WittyPi Mini	1	13 €
3	Microphone	Soundspectrum	Adafruit	I2S MEMS SPH0645	1	5 €
4	Temperature	Inside Temp.	Keyestudio	DS18B20	1	4 €
5	Humidity + Temperature	Outside data	Aosong Electronics	DHT22 (AM2302)	1	5 €
6	A/D Converter	Convert analog signal of load cell to digital		Hx711	1	8 €
7	Load cell	Weight measurement	BOSCHE	H30A (150kg)	1	50 €
8	Header Pin	Socket connection		1x40 pin - Long	2	2 €
9	Platine PCB		chapter 2.4	2 Layer	1	2 €
10	SDCard	Storage	Intenso	microSD	1	4 €
11	Cases				2	5 €
12	Aluminium plate large	Plate for Scale		150x100x10 mm	2	4 €
13	Aluminium plate small	Plate for Scale		35x35x6 mm	2	3 €
14	Mobile GSM Wi-Fi Router	Uploading Data via GSM	HUAWEI	E5330	1/10	30 €
15	Other small components	Screws, glue, etc.			1	5 €
16		Port D-Sub9 Female, DC to DC Conv, Spacer, Resistor, Socket Raspi, Jack D-Sub9 Male			1	13 €
17		Spacer, Cable, Port Input & Output,			1	20 €
					Total	**170 €**

2.7 Sustainability

Sustainability is a key factor in the decision to choose modular components instead of mini PCBs with surface-mounted device (SMD) components. All components can be reused. The Raspberry Pi, Witty Pi and Hx711 are connected using breakaway female headers (see Figure 15) and the corresponding male headers. This enables a non-destructive disassembly of the components from the PCB if necessary. From the PCB only the small amounts of copper can be recycled. The FR4 epoxy glass laminate which makes up the bulk of the bare PCB cannot be recycled back to its constituents. The SAMS HIVE cases are printed with ABS and are also recyclable. ABS compounds (Acryl-Butadien-Styrene) are especially characterized by their high heat resistance, high chemical resistance and good weather resistance. ABS plastics have excellent welding and bonding properties and are otherwise easy to process.

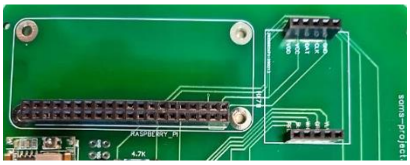


Figure 15: PCB female header

A Raspberry Pi Zero W was chosen as the single-board computer to ensure the greatest possible benefit when it comes to further use. The Raspberry Pi is developed to promote teaching of basic computer science in schools and in developing countries. It is now widely used even in research projects because of its low cost and portability. A large community of developers works together on a variety of open source projects. For example, a simple reuse would be to use the hardware components as well as the open source SAMS software in educational institutions, schools or makerspaces to further develop bee monitoring (see SAMS Partnerships WP6). Another aspect of hardware selection is the lifespan of the components. Thus, high quality was taken into account. The lifetime of the Raspberry Pi, for example, is assumed to be that of a computer, i.e. more than 10 years. Component damage is caused by oxidation of the connections while the SD card is susceptible to damage due to the number of read/write accesses.

3. Software

3.1 Open Source Licence

The entire software code plus all CAD files for production of the PCB, the sensor frame and the computer case as well as a wiki page are freely available under the open source MIT license (see below) and can be downloaded from our Github site: https://github.com/sams-project.

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3.2 Calibration

The calibration of the HIVE system is done via a standard browser on the computer or smartphone. The calibration interface is accessible via the IP address of the HIVE system (Figure 16). There the user credentials for the secure transmission of data to the DW can be entered. The balance is also calibrated with a reference weight. The user is guided through an intuitive menu. Additional settings can be made via Online Configuration in the DW (Chapter 3.5). The settings are displayed in the interface. This includes the available memory space on the SD card as well as the signal strength of the WiFi to change the position of the router if necessary. In addition, the weight can be tarred and all settings can be reset. It is recommended to have the calibration and the settings implemented by a system administrator and to give the systems preconfigured to the end users. In this way errors can be excluded and a functional use is ensured. Figure 16 shows a sample of the calibration interface.

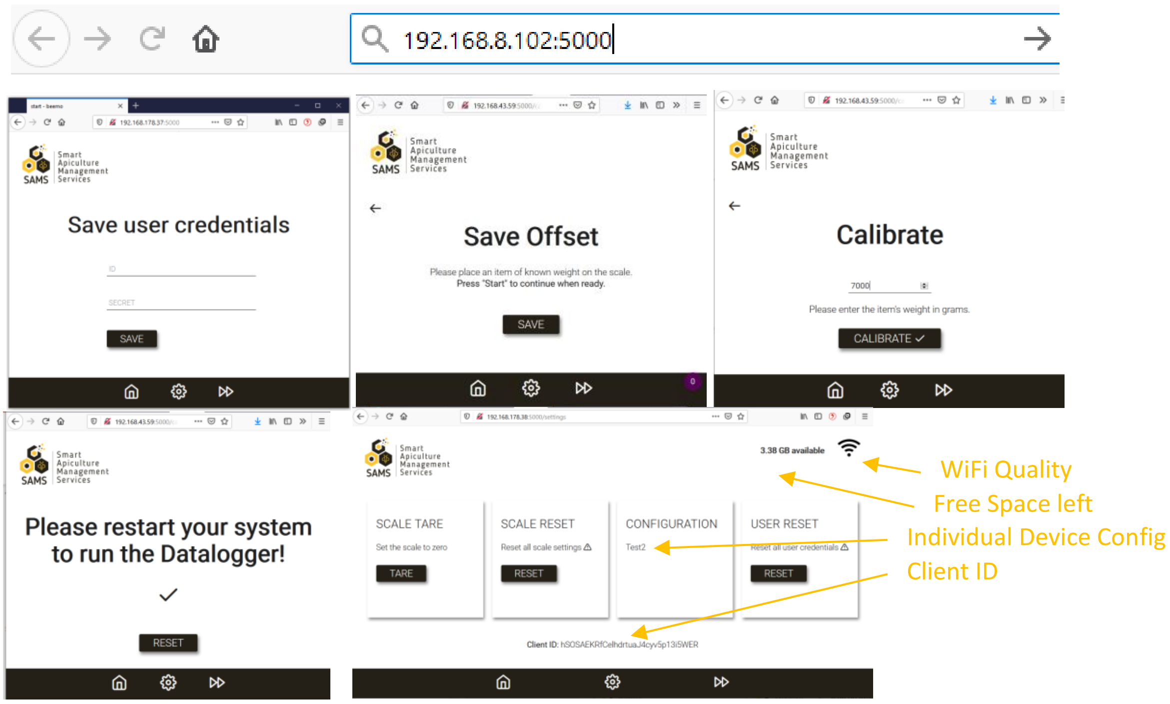


Figure 16: SAMS HIVE system WebApp user interface

3.3 Features

Besides the basic functions, the SAMS HIVE System offers additional features. The basic functions are sensor data recording of temperature, humidity, weight and acoustics, as well as WiFi data transmission to the DW. For the acoustic data the audio recordings are converted into FFT spectral data. The conversion of the audio data is mainly done for reasons of data protection and reduction of the data volume. Advanced features include:

- **Online Configuration**: Key parameters such as measurement interval or asymmetric measurement schedules can be adjusted in the DW for specific user groups or individual HIVE systems (Chapter 3.5, Figure 17)

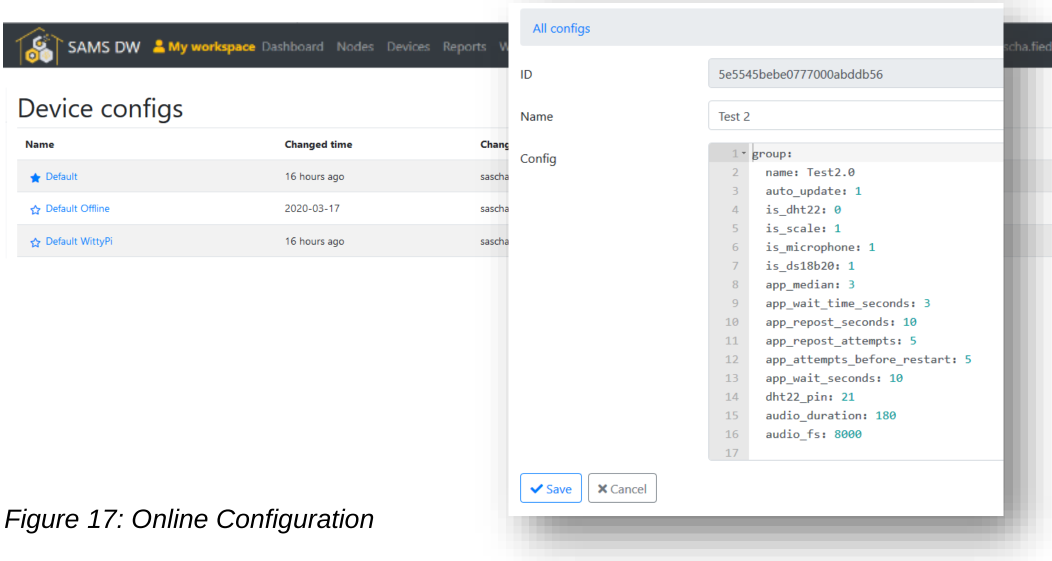
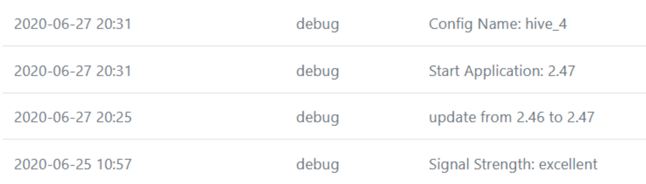


Figure 17: Online Configuration

- **Debug mode**: In debug mode (Figure 18), information about the voltage supply of the photovoltaic battery, the signal strength of the WiFi, errors, name of the selected online configuration, version number of the app, update process, reboot if necessary, warnings if sensor should be checked, error if access denied (check credentials) is shown.



2020-06-27 20:31	debug	Config Name: hive_4
2020-06-27 20:31	debug	Start Application: 2.47
2020-06-27 20:25	debug	update from 2.46 to 2.47
2020-06-25 10:57	debug	Signal Strength: excellent

Figure 18: Display of messages in the data warehouse during the Debug mode with automatic update

- **Automatic update process**: After each measurement, the system is checked for new updates and, if necessary, the latest firmware version is automatically downloaded and installed (Figure 18).

- **Calibration and Setting User Interface (WebApp)**: A dedicated WebApp was developed for the calibration of the HIVE system (Chapter 3.2)

- **Self Test Interface**: A Self Test Interface is offered for functional testing after calibration.

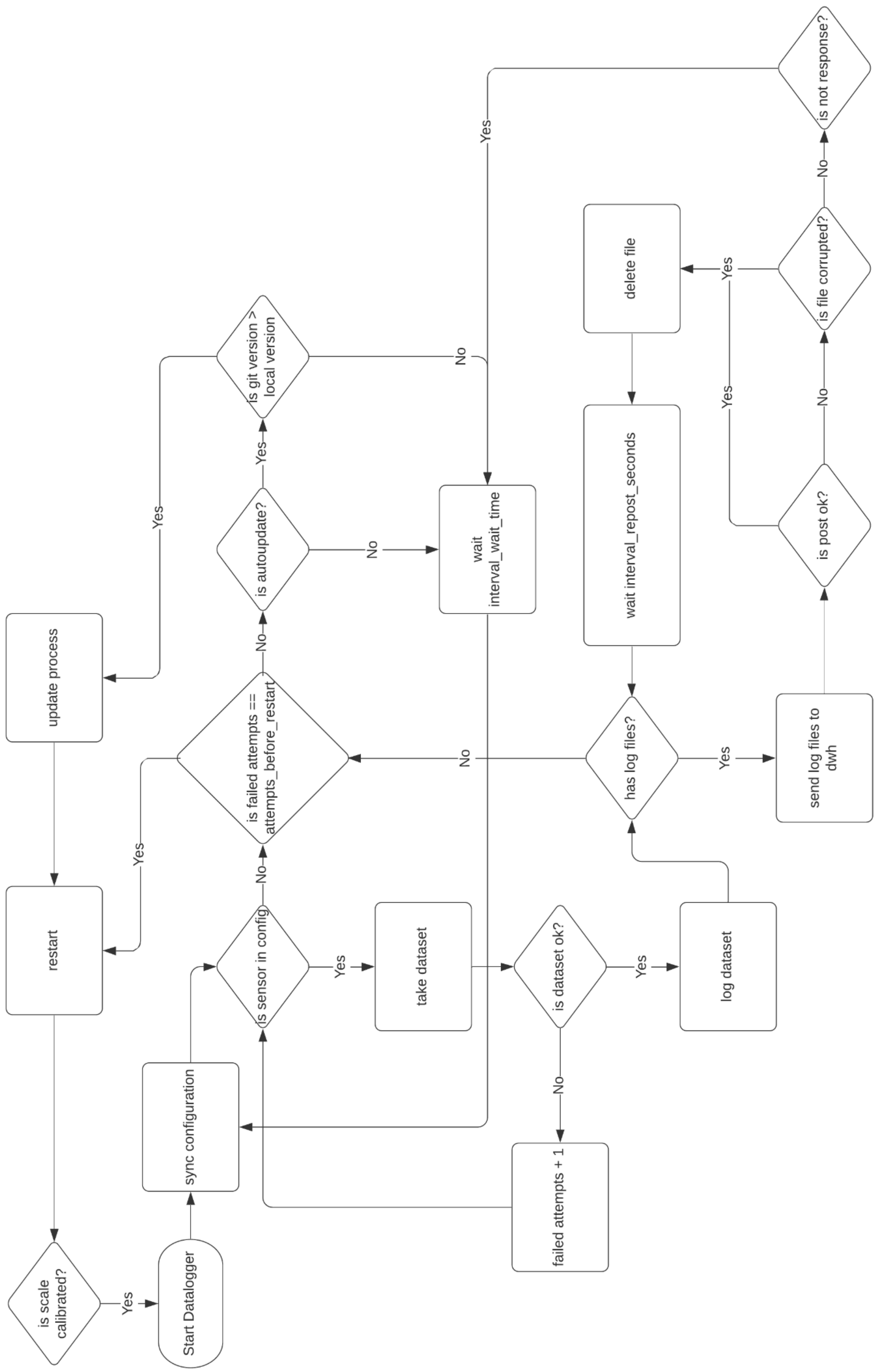
- **Status display**: After the release of the next version 2.48 in September, various status messages will be displayed via an RGB LED in the case. The function can be activated via the Online Configuration.
- **Offline Mode**: In offline mode all datasets are stored on the SD card and can be read from it. Either manually via ssh or via USB interface and the customized UNILV firmware (Deliverable 4.3)

3.4 Process

In the following, the software process after the configuration and the start of the measuring process is briefly described in words. A software flow chart illustrates it additionally. This process describes a complete measuring interval. The distance of such measuring intervals can be adjusted by using the online configuration in the field 'app_wait_seconds' or the energy management with wittyPi 3 mini.

1. if debug is on: send following debug information:
    - Config version
    - Config Name
    - Signal strength
    - Voltage (vOut and vIn from wittyPi if installed)
2. check if system has valid access token
3. write online status (true or false)
4. if online: synchronise configuration with online config if exists
5. check if ignore_error
6. append sensors from config list
7. start get sensor data
8. if sensor data valid, try to send this data
9. if status code 200: (data accepeted) then the system jump to step 9)
10. if status code 400: delete the dataset
11. if status code not 200 or 400, the system save the dataset (refer to save feature) and switch to offline mode
12. if sensor data is courrupt, send error message to DWH ([SENSOR] failed!) and delete the dataset
13. try to post log files to DWH
14. if response 200: delete the dataset
15. if response 400: delete dataset (redundant to point 7.)
16. if not repsonse: return false
17. if repsonse from logfiles are false: add one failed attempt
18. if failed attempts > app_attempts_before_restart (in config): send error message to DWH **(**Too many errors: reboot system!**)**
19. check for update and if auto_update true:
20. pull the new update.py
21. write update file to recnognize the new update after restart
22. restart
23. the system will recocnize the new update and execute the new update.py
24. restart
25. if auto_shutdown: shutdown the system
26. wait app_wait_seconds before begin the new cycle

Software flow chart



3.5 Online configuration

This section describes the setting options of the Online Configuration in the DW. Next to each code fragment the default value and a short description are given. Online changes are automatically adjusted by the HIVE system before each measurement. Even complete Witty Pi scripts can be inserted and activated directly.

```
0 = false
1 = true
```

- name: DEV **(Name of the Configuration)**
- timezone: Europe/Berlin **(Timezone needed for Datasets)**
- auto_update: 1 **(Automatic Update)**
- auto_shutdown: 0 **(Automatic shutdown after a measurecycle)**
- ignore_error: 0 **(Error shown in the DWH)**
- debug: 1 **(Debug messages shown in the DWH)**
- is_dht22: 1 **(Measure DHT22 data)**
- is_scale: 1 **(Measure Loadcell data)**
- is_microphone: 1 **(Measure Microphone data)**
- is_ds18b20: 1 **(Measure DS18B20 data)**
- app_median: 3 **(Number of measurements for the sensors to calculate the median)**
- app_attempts_before_restart: 2 **(Number of errors before restarting)**
- app_wait_seconds: 60 **(Seconds that the system waits before starting new cycle)**
- dht22_pin: 23 **(GPIO Pin for DHT22)**
- audio_duration: 10 **(Seconds that the system collects audio data)**
- audio_fs: 8000 **(Samplerate for the Microphone)**
- wittypi: [complete Witty Pi schedule script] **(Script for individual ON/OFF routine)**

3.6 Automatic error control

Sensors are checked for errors within each measurement routine. Errors are logged in the internal log and sent to the DW if the debug function is active. Similarly, after an adjustable number of failed attempts, defective sensors are automatically switched off and a warning is sent. In the following, the warnings and their function are shown:

- `Failed to initialize [SENSOR]`: Sensor is broken or the wiring is not correct

- `Cannot get Scale data: [ERROR MESSAGE]`: Something is wrong with the wiring of the scale or the load cell is broken
- `Failed to insert log files: [ERROR MESSAGE]`: Writing the log file failed
- `Failed to read log files: [ERROR MESSAGE]`: Reading the log file failed
- `Failed to post log files: [ERROR MESSAGE]`: Exception while posting the Log file. Broken pipe or similar
- `[SENSOR] failed`: Sensor is broken or sends no valid data (Similar to "Failed to initialize [SENSOR]"
- `Too many errors: reboot system!`: Failed attempts of the System is >= "attempts_before_restart" in the config. This happen, if a Sensor failed. The system remembers the sensor and excludes it at the next restart

4. Evaluation

4.1 System implementation

The SAMS HIVE system has been implemented on 3 continents in 5 countries. In Europe at 6 different locations in Romania, Latvia and Germany. In Asia on West Java, Indonesia at 7 different locations and in East Africa in Ethiopia at 11 different locations. Within several implementation workshops in Indonesia, Ethiopia, Latvia, Germany and Romania, trainers were trained to be able to give workshops on system implementation. The first workshop took place in March and April 2019 in Indonesia and Ethiopia. Different errors, such as GSM problems led after some time to the discontinuation of the measurement. Error sources were considered and adapted during the further development. Previously known software bugs were removed and a PCB was developed for easy implementation. In July 2019 further implementation workshops for training of trainers took place in Bandung, Indonesia and Holeta, Ethiopia. Further systems were built together and partially implemented.

Furthermore local markets and dealers were visited to find equivalent components locally and to adapt the system design to local conditions. For instance, the control unit was tried to be replaced by an alternative energy management system based on a microcontroller and finally replaced by the use of Witty Pi, some systems were connected to the local power grid if possible, the photovoltaic system was produced with locally available materials and components, local prototyping circuit boards as well as plugs and cables were used, different cases were tested and extended with status LED, a custom PCB was designed to be produced with local technology, finally customized acrylic laser cut for casing was used. In parallel, UNILV developed an alternative system, which is fully adapted to the local resources and based on a NodeMCU with ESP8266 CPU instead of using the single-board computer Raspberry Pi (Chapter 4.8). Due to the slim and energy-saving design, an acoustic sensor had to be avoided. In order to obtain an extended data basis for the development of the DSS, however, the focus is still on the HIVE system including acoustics. A further workshop phase was planned for spring 2020 and had to be cancelled due to COVID19. This delays the implementation. A further implementation phase is planned for Sept/Oct 2020. In Indonesia 7 of the 50 systems are actively implemented, 24 more are expected to be implemented in

September. For 26 systems, however, no partner beekeeper has been found in Indonesia yet for the care of bee colonies with HIVE system. In Ethiopia, 13 of the 50 HIVE systems are actively implemented, 37 more are expected to be implemented in September/October. In the EU, 16 of the 20 systems are actively implemented. Another 4 systems will be implemented in September, e.g. with an organic beekeeper as future SAMS partner in Romania. The status of the respective implementations is shown in table 6.

Table 6: Implementation status of HIVE Systems

Date	Country	Site	N° of systems installed	Transfer of data (active)	Technical problems, if no transfer possible
March 2019	GER	UNIKAS Research Station, Witzenhausen	5 systems	Data mostly sent stable from May 2020 - still running	Software interruptions, Connection error
March 2019	ID	D´bees, Ciwidey, West Java	2 systems	Data sent from early March 2019 to mid July 2019 Discontinued due to dry season and bee colony loss.	GSM connection problems
March 2019	ID	Baabusalam Apiary, Ciburial, Bandung, West Java	1 systems	Data mostly sent from September 2019 - December 2019 with interruptions. discontinued due to dry season and bee colony loss.	One of the problems was related to the Raspberry Pi WiFi connection to the router (could not connect).
March 2019	ID	Tani Kota, Bandung, West Java	2 system	Data mostly sent from April 2019 - October 2019 with interruptions. Discontinued due to dry season and bee colony loss.	One of the problems was related to the Raspberry Pi WiFi connection to the router (could not connect).
Apr 2019	ET	Holeta	5 systems	not activly sending at the moment	lo-fi Prototypes
July 2019	ET	Bako and Menagsha research stations	8 systems	Not active, will be checked in Sept 20	Failure of 3G network after some time Two out of ten systems could not be installed due to technical problems (will be re-installed with 35 further systems in Sept 2020)

Ongoing	GER	Potsdam, Brandenburg	1 system	Sending data when online	Offline data have to read out
April 2020	GER	Göttingen	1 system	Sending data from empty hive	Bees swarmed in May. No new bee acquisition due to COVID19. Planned acquisition in Sept 20
May 2020	ET	Addis, Ginchi, Ambo Bonga	37 systems	Plan to be implemented	Date changed due to COVID19. New date as soon as possible (Sept/Oct 20)
June 2020	GER	Witzenhausen	4 systems	Sending data June 2020 —still running	
July 2020	LATVIA	Jelgava	5 systems	Sending data July 2020 —still running	
July 2020	ID	Madu Maribaya, Lembang, West Java	2 systems	Sending data July 2020 —still running	
Aug 2020	ID	D'Bees, Ciwidey, West Java	5 systems	Plan to be implemented	Delay due to COVID19
Aug 2020	ID	Ciamis, West Java	3 systems	Plan to be implemented	Delay due to COVID19
Sep 2020	ID	Madu Maribaya, Lembang, West Java	6 systems	Plan to be implemented	Delay due to COVID19
Sep 2020	ID	Ciburial, Bandung, West Java	3 systems	Plan to be implemented	Delay due to COVID19
Sep 2020	ROMANIA	Jud. Sibiu,	1 system	Plan to be implemented	
Sep 2020	GER	Soest	1 systems	Plan to be implemented	
Sep 2020	GER	UNIKAS Research Station, Witzenhausen	2 systems	Plan to be implemented	Delay due to COVID19
as soon as possible	ID	-	26 systems	Plan to be implemented	Delay due to COVID19. No partners yet

4.2 Issues and challenges

In Latvia and Germany hardware is installed for system testing and debugging purposes. Systems installed in Latvia and Germany are working properly, which means that the connection between hardware and SAMS Data Warehouse is operating well.

Nevertheless, data collection and transfer from the target countries Ethiopia and Indonesia to the SAMS DW is not happening as it was expected due to different reasons in the countries. Such reasons are:

- One of the problems in Ethiopia was related to 3G mobile network coverage. The provided router for the system cannot send data due to mobile network problems (possibility that the router could not switch to a reliable network, 2G in this case). It was agreed that a router with capabilities to use 2G network for data transmission will be used instead. Installation process was planned for March 2020 in Ethiopia and April 2020 in Indonesia. Due to the corona virus outbreak it was not possible to do that and is postponed until further notice and reduction of restrictions. The components were partly handed over to the partners at the Steering Committee Meeting (SCM) in April 2020. Some of the construction parts had to be sent by mail. In Ethiopia there are problems to get the shipment out of customs due to travel restrictions by COVID19.
- Due to challenges in maintaining stable connectivity and a lack of IT expertise near the installation sites of Holeta and Gedo in Ethiopia for applying a quick solution/ fixing the problems systems are not operating.
- The biggest issue in Indonesia is related to the absconding of bees. Many bee colonies of our partner absconded due to the dry season that lasted until the end of 2019 in Indonesia.
- One of the challenges for both countries is the mobile network operation for data transmission. Network stability issues and frequent interruptions have been observed.
- The location of the apiaries also plays a significant role from device maintenance (error fixing, system updates, additional sensor set-up etc.) point of view. In Indonesia the apiaries are located far in forests and mountain areas where traveling is time-consuming.
- It is concluded that the option for local storage of measurements is necessary to mitigate the data transmission problems. It is clear that in this case real-time decisions could not be made, but historical behavior of the colony would be available.
- Unfortunately, until today there was no constant monitoring system available in Ethiopia and Indonesia. To be able to gather offline stored data, partners from UNILV developed a solution for convenient offline data transfer from the local bee colony monitoring device to the flash drive.

4.3 Functional testing

Table 7 lists all functional tests conducted on the SAMS HIVE systems in cooperation with the project partners. UNIKAS performed the majority of them. Short-term tests refer to tests within one day, mid-term tests with up to 2 weeks duration, long-term tests were carried out for more than 4 weeks. The definition 'default mode' includes a SAMS HIVE system with active Witty Pi default schedule script as described in Report 3.5 (in Chapter 3.4 Witty Pi Setup).

Table 7: Functional testing

Functional test	Method	Result	Comment	Test positive
Photovoltaic System: Component dimensioning, especially solar module power and battery capacity with HIVE system	Mid-term test, 50 Wp solar module, 100 Ah, 10 SAMS HIVE systems run in default mode	Photovoltaic system sufficiently dimensioned	Depending on weather conditions and global solar irradiation	x
Photovoltaic System: Component dimensioning, especially solar module power and battery capacity with HIVE system	Long-term test, 80 Wp solar module, 100 Ah, 5 SAMS HIVE systems run in permanent ON mode with 5 min intervall	Photovoltaic system sufficiently dimensioned	Depending on weather conditions and global solar irradiation	x
WiFi connection: Data transmission between HUAWEI E553 and SAMS HIVE system	Mid-term test, 10 SAMS HIVE systems run in default mode	WiFi router works fine up to 10 systems	Not more than 10 possible	x
Data transmission: between Data Warehouse and SAMS HIVE system	Mid-term test, 10 SAMS HIVE systems run in default mode	Data transmission works fine	Data Warehouse Nodes have to be set up; SAMS HIVE System needs to be calibrated	x
System measuring intervals: Setting of different measuring intervals	Short-term test, measuring intervals from 60s to 15 min without Witty Pi, 1 SAMS HIVE system	Measuring intervals adaption works fine	Settings can be changed via online configuration in Data Warehouse	x
Witty Pi Script: Use of Witty Pi schedule scripts to controll system ON/OFF cycles	Mid-term test, 5 different schedule scripts, 1 SAMS HIVE system, online configuration interface	Schedule script usage works fine	Note: to change config you should select a new config via the DWH nodes	x
Witty Pi and auto_shutdown function: Witty Pi schedule script with WAIT syntax, online configuration value for auto_shutdown = 1	Short-term test, Witty Pi schedule script with WAIT syntax, online configuration value for auto_shutdown = 1	Bug in combination with Internet cut, otherwise it works fine	Does not work in combination with Internet cut	(x)

Offline function: Data storage while internet cut and upload with re-connection	Short-term test, cut power to WiFi router, test while measurement and between intervalls, 1 SAMS HIVE system	Bug in combination with WAIT syntax, otherwise it works fine	Does not work in combination with WAIT syntax in Witty Pi schedule script and auto_shutdown = 1; no measurement during upload	(x)
Online configuration: Change settings via the online configuration interface in the Data Warehouse	Short-term, change settings and controll adaption on 1 SAMS HIVE system	Works fine	Note: to change config you should select a new config via the DWH nodes	x
Sensor error: Error detection of sensor disturbance	Short-term test, sensor data connection removed, app_attempts_before_restart = 2	Error was detected and sensor switched off after 2 failed attempts		x
Temperature sensor DS18B20: more DS18B20 simultaneously	Short-term test, 1 SAMS HIVE systems run in default mode, 5 DS18B20, 1 m cable length each sensor	System works fine within several temperature sensors parallel	Sensors must be connected one after the other, identified and implemented in the Data Warehouse	x
Temperature range: Function not restricted within specified temperature range	Short-term test, temperature range from - 5°C - 40°C, 1 SAMS HIVE system	System works fine within the temperature range		x
Temperature measurement: Recording of temperature data over a longer period of time	Long-term test, 3 SAMS HIVE system run in default mode	The smaller the bee colony the more probable is the mixture with outside temperature	Function depends on the position of the sensor in the beehive. The sensor should be located centrally in the bee colony	(x)
Acoustic measurement: Recording of acoustic data over a longer period of time	Long-term test, 5 SAMS HIVE systems run in default mode	The smaller the bee colony the more probable is the dominance of outside noise	Function depends on the position of the sensor in the beehive. The sensor should be located centrally in the bee colony	(x)

DHT22 vs. DS18B20: Recording of temperature data with DS18B20 and DHT22 over a longer period of time	Long-term test, 5 SAMS HIVE systems run in default mode	Possible deviations of up to 1°C. Temperature course however very similar	One of the sensors can be used as outside temperature sensor. We recommend to use DS18B20 aus outside sensor, since it is waterproof	x
Humidity measurement: Recording of humidity data over a longer period of time	Long-term test, 5 SAMS HIVE systems run in default mode	Humidity fluctuates in beehive between 40 and 70%	Humidity measurement in the bee colony makes sense	(x)
Weight measurement: Recording of humidity data over a longer period of time	Long-term test, 5 SAMS HIVE systems run in default mode	Weight data sometimes fluctuate by a few kg during several measurements. However a clear curve is visible	The data can be used for evaluation. However, the fluctuation should be eliminated	(x)
Temperature compensation (UNILV): Influence of the outside temperature on the hardware (load cell and hx711) to the measurement results	Short-term test, 1 SAMS HIVE systems run in default mode	Result is influenced by the outside temperature by +/- 20g per °C	Effect is reduced via software. Result can be used for evaluation. However, temperature compensation should be revised	(x)
Long-term test overall: General function test of the overall system	Long-term test of 10 SAMS HIVE systems in default mode	Measuring error/ system break down possible 1/1000h, risk exists	Restart solves problem, Error is not yet located	(x)

4.4 Protocols

Regular protocols for data analysis were written for all investigated bee colonies at UNIKAS with SAMS HIVE system. There were weekly routine checks on all colonies. They included date and time, colony size, number of brood combs, presence of queen, eggs, larvae and brood, honeycomb consistency, temperament, swarm tendency, diseases, treatments, food, varroa count, as well as other parameters and comments. The protocols are not published here.

4.5 Data

In the following some exemplary sequences of the data reports generated by the Data Warehouse are presented to illustrate the functional tests as well as the collected data. Figure 20 shows the comparison of the sensor data of DHT22 with DS18B20 for temperature measurement. A small deviation of up to 1°C is visible. Both sensors were installed at the same place in the colony in a SAMS sensor frame (Chapter 2.3). Figure 21 shows the comparison of the temperature and weight patterns of three bee colonies over several days and during a swarm event in Hive 5 at noon on 8 June. A significant weight loss of several kg correlates with a temperature increase of 1°C, followed by a slight temperature decrease over the same period. Figure 22 shows the event in Hive 5 in detail from 10:00 a.m. to 3:00 p.m. After a gentle temperature drop after the event, the temperature stabilizes again. Further experiments and more data of similar events are necessary to successfully use the findings for the implementation of a DSS. Figure 23 shows temperature and weight curves in a bee colony over several months of the season 2020 and during the honey harvest on 16 June. The honey harvest is characterized by a weight loss of 24 kg. The post-harvest temperature fluctuation is probably due to further work on Hive 4 during this period 10 June - 15 June. Figure 24 shows the characteristic temperature and weight change during and after a disturbance caused by a routine check on 10 July. Figure 25 shows the characteristic curve of unamplified sound pressure level over the frequencies of 100 - 1000 Hz during the swarm event on 8 June in Hive 5, recorded with SAMS HIVE microphone I2S MEMS SP0645. For reference, all bee colonies were equipped with high quality microphones. In the following the acoustic evaluation and modelling is described in more detail.

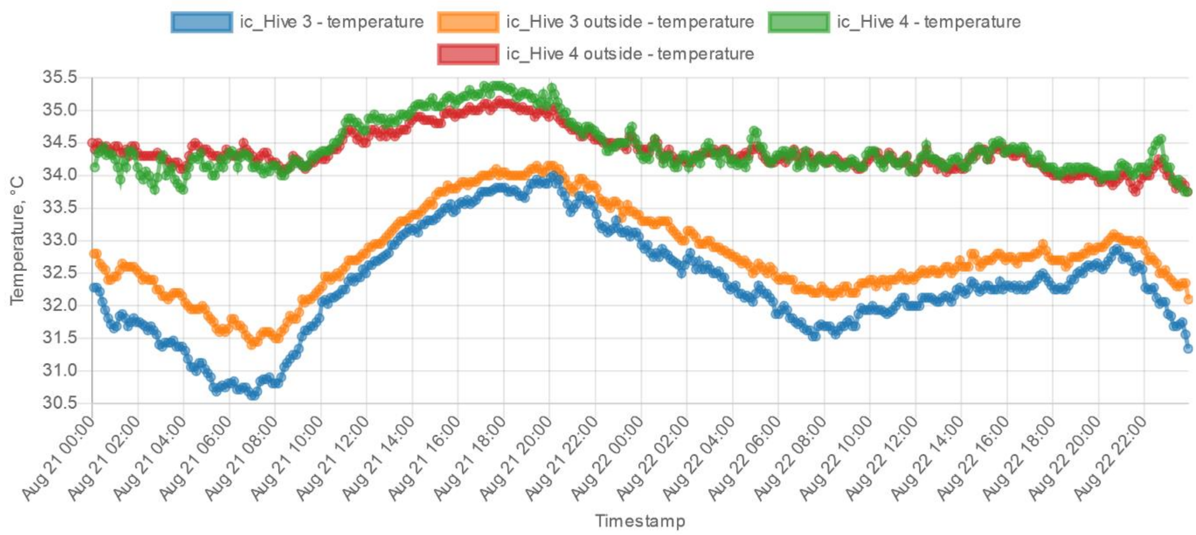


Figure 19: Comparison of sensor data DHT22 vs. DS18B20 temperature in 2 Hives within 48 hours

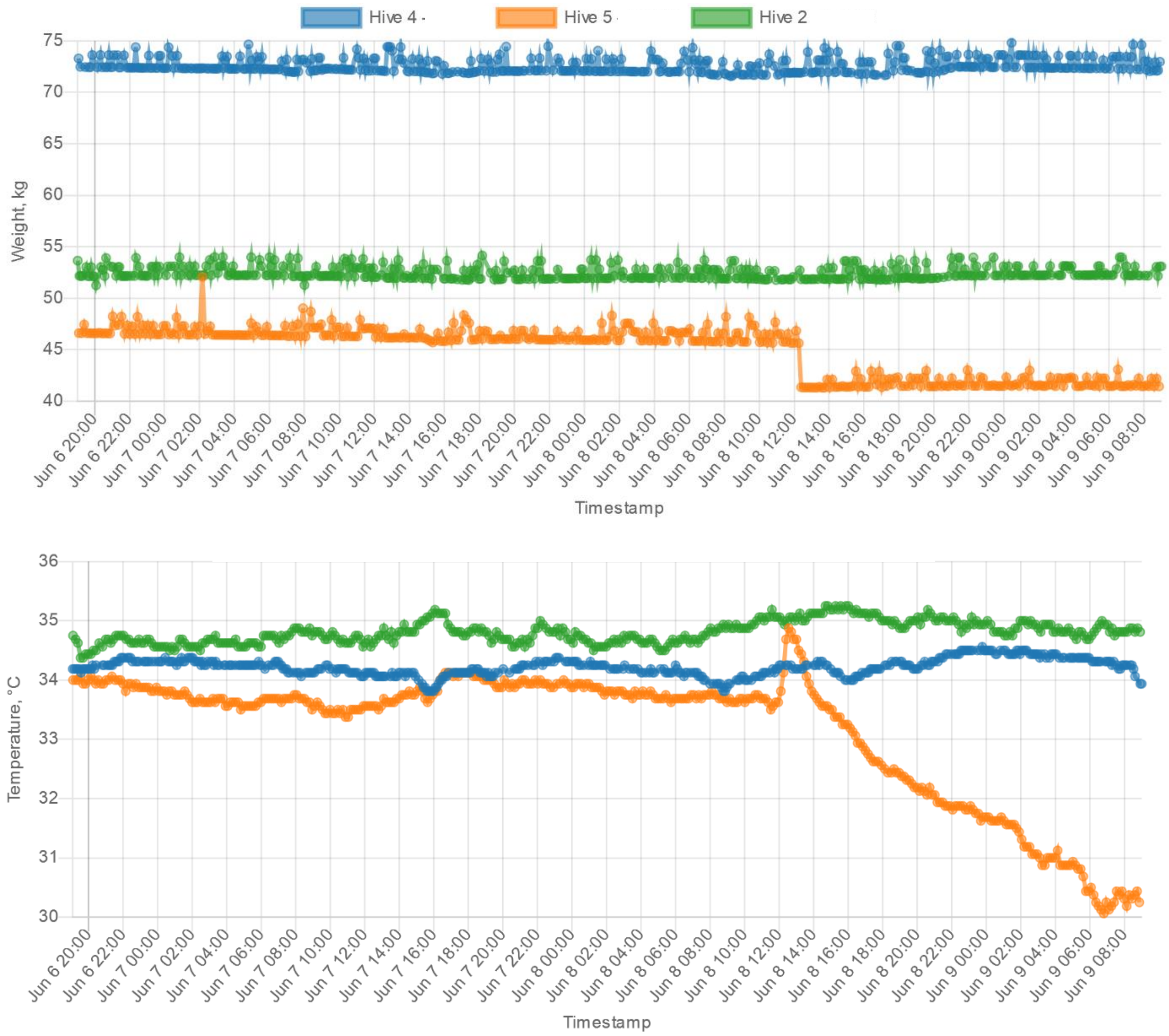


Figure 20: Comparison of the temperature and weight patterns of three bee colonies over several days and during a swarm event in Hive 5 at noon on 8 June. (Recorded with SAMS Monitoring System at the apiary of UNIKAS, 2020)

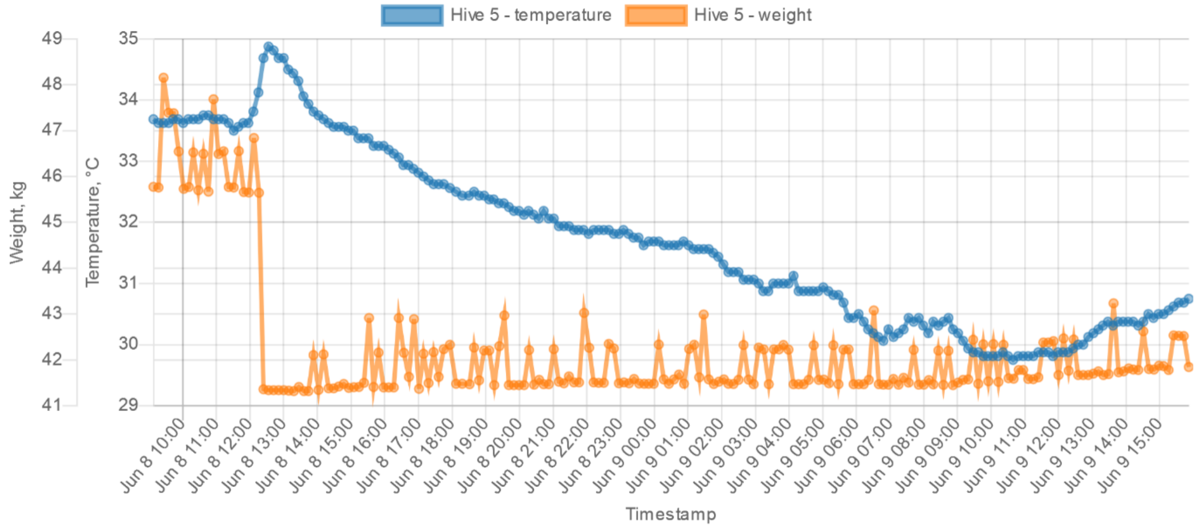


Figure 22: Temperature and weight patterns in detail during the swarming event in Hive 5 on 8 June (Recorded with SAMS Monitoring System at the apiary of UNIKAS, 2020)

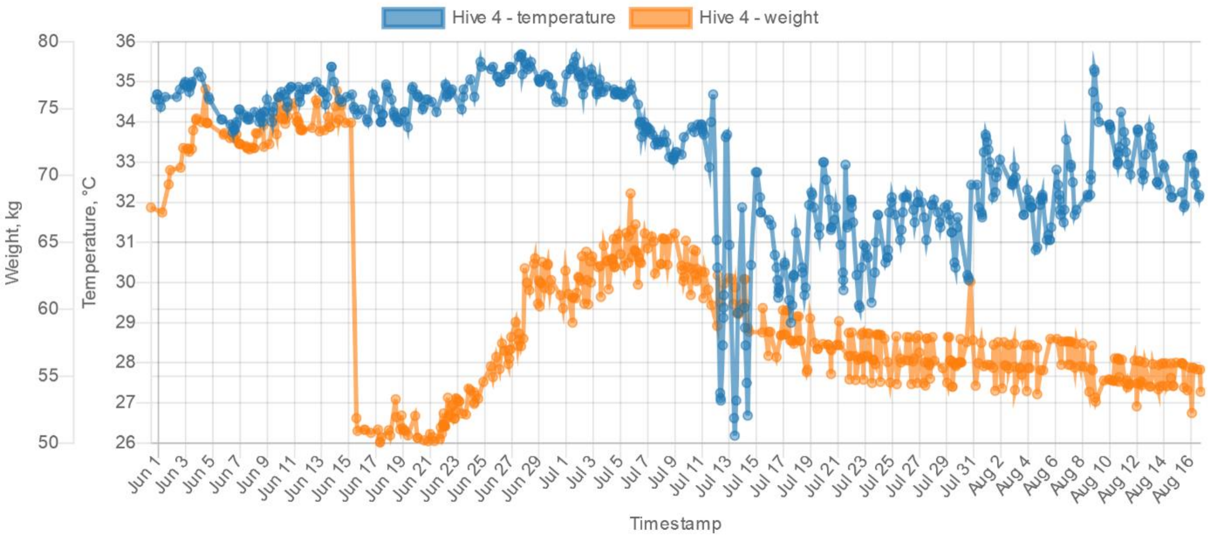


Figure 21: Temperature and weight curves in a bee colony over several months of the season and during the honey harvest on 16 June (Recorded with SAMS Monitoring System at the apiary of UNIKAS, 2020)

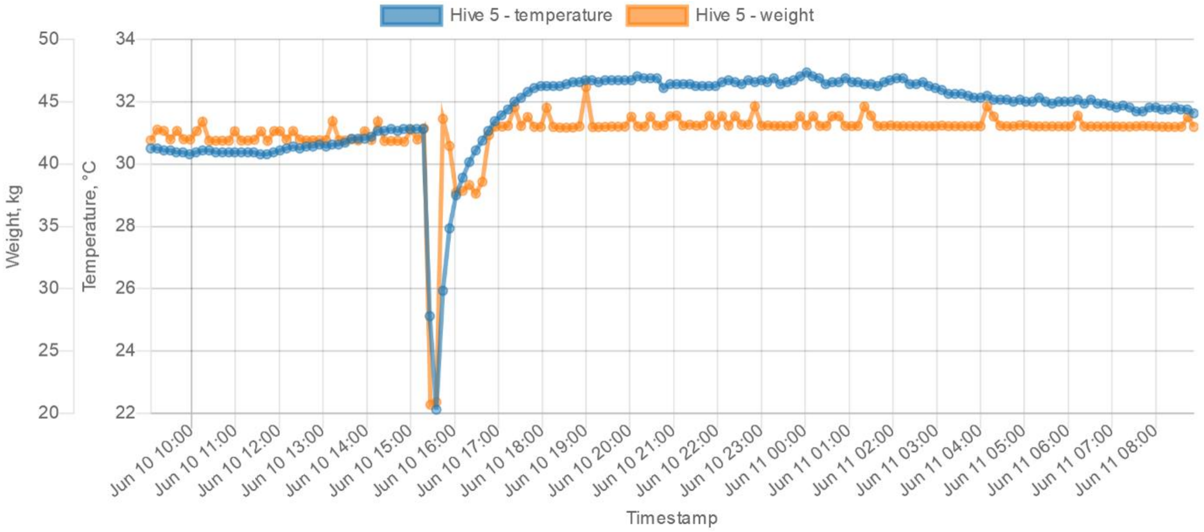


Figure 23:Characteristic behavior of temperature and weight after a disturbance in the bee colony, shown here a regular inspection in the afternoon of 10.07.20 (Recorded with SAMS Monitoring System at the apiary of UNIKAS, 2020)

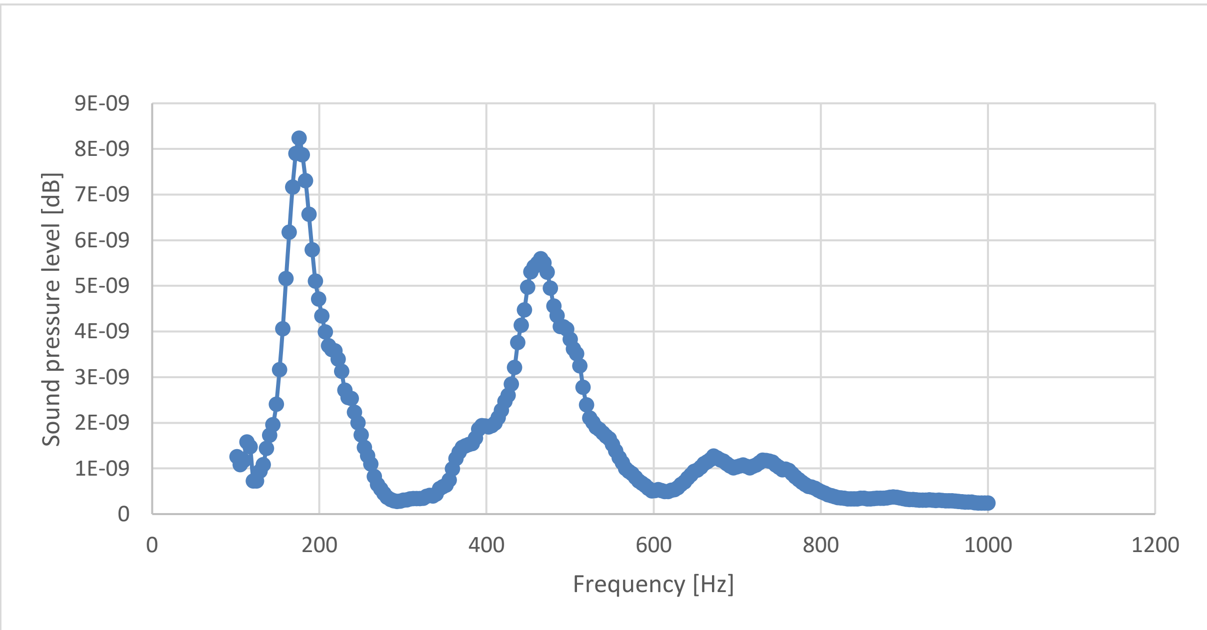


Figure 24: Characteristic curve of unamplified sound pressure level over the frequencies of 100 - 1000 Hz during a swarm event (recorded with SAMS Monitoring System at the apiary of UNIKAS, 2020)

The beehives of the University of Kassel are equipped with high-quality microphones. These record the airborne sound inside the hive. The recording is done with a sample frequency of 44100 Hz at a resolution of 16 bit. The recording of the sound inside the hive is continuous. Each 10 min are combined to a wave file. Currently 7 hives are observed, an 8th hive is empty. The empty measurement is used to record the ambient sound independent of the noise of the bees. This information could later serve as a filter. The 8 measuring channels are combined to an 8-track wave file.

Currently, nominal and/or ordinal variables are used as response variables, which represent characteristics of the system such as summer/winter, day/night, swarm tendency, general beekeeping condition of the hive.

The Random Forest Algorithm is used to create the first model, as it allows a good quantification of the explanation of variance of the individual available influencing variables. At present, it cannot yet be judged whether the random forest algorithm has the highest merit for a final model. Figure 26 shows an example of the feature generation “Dominant Frequencies”. Two Frequencies are dominant in the relevant frequency range up to 1 kHz.

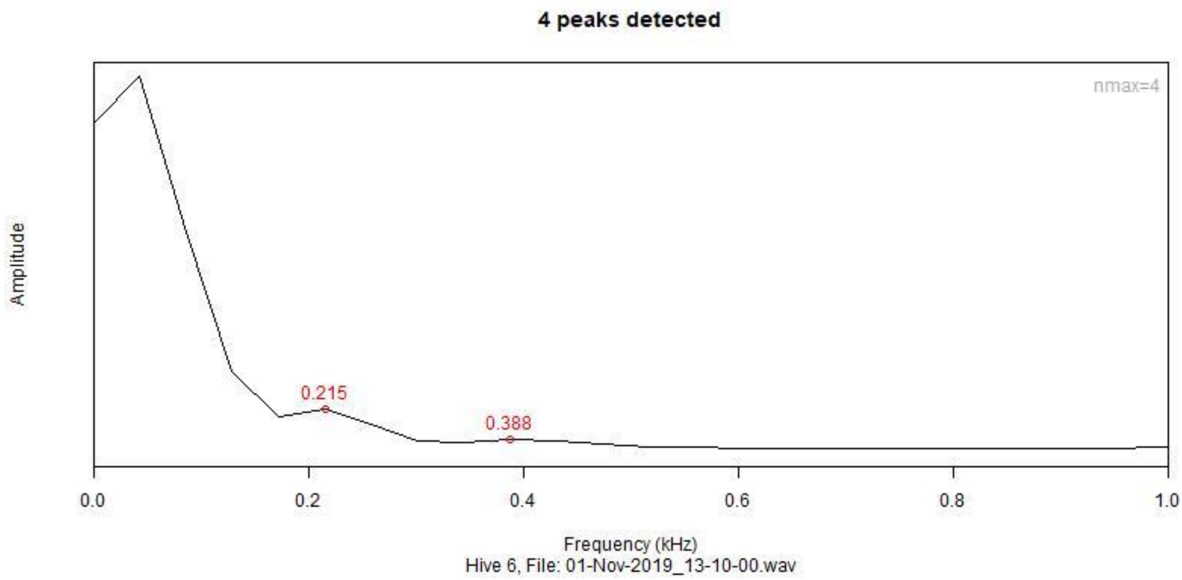


Figure 25: Example of the feature generation “Dominant Frequencies”. Two Frequencies are dominant in the relevant frequency range up to 1 kHz

In the final stage, several models nested as an expert system are certainly needed to make the complexity of bee’s behavior in the hive predictable.

The main challenge of the approach described above is the time critical calculation of the described variables using the R-script. The preprocessing of an 8-channel sound file with 10 min content currently takes 3.5 min. And this does not yet include the following modelling. This means that for the preparation of the data of one year, about 4 months of computing time are necessary at the moment.

A further challenge arises from the circumstance described above. Due to the current long computing time, a subsample of observations must be made from which models are derived. A small sample size for model building with machine learning algorithms is again associated with the danger of generating biased models. This means that the probability to build a model based on a biased sample and not to capture the true dispersion of the system increases.

This underlines the need for cyclical model simplification. We work with the hypothesis that the modelling approaches will gradually lead to a simple model. A simple model would then also require fewer pre-processing steps and thus less computing time.

In parallel, work is also being done on the more efficient programming of the current pre-processing.

There are at least two objectives that justify the effort of the modelling described above:

1. Cyclic modelling potentially opens up the possibility to build a mechanistically deterministic and thus more robust model, since causalities are understood step by step on the way of modelling.

2. A simple set of models and the underlying expert system may possibly also run on the Raspberry Pi system, so that the amount of data to be transferred to the database can be kept small and the data structure to be transferred can be simplified.

4.6 Market analysis and business potential

The market analysis here deals with the comparison of different bee monitoring systems with the SAMS HIVE system in order to facilitate an assessment of the potential. The analysis is mainly based on the information provided on the website http://colonymonitoring.com/ and was conducted rudimentarily as an auxiliary tool, it is not based on a scientific approach. The website highlights 7 providers of bee monitoring systems among a large number of vendors and projects, which also make use of acoustic recording in the bee colony. However, only 3 of them are products with similar sensor configuration as the SAMS HIVE. From those again only one provider is also open source and makes its codes and building instructions available online. At this point we would like to refer to their website: www.osbeehives.com. Another project with great potential is the community of https://hiveeyes.org. For some time now, valuable information from various projects has been collected there and research has been conducted on their own hardware and software development in the open source community. The project on the site https://beelogger.de has very good open source manuals and advanced low-cost hardware, but so far without acoustic sensor. The potential for SAMS to become one of the few open source systems on the market and attract the business sector is therefore large, despite the rapidly growing number of alternative products in this segment. Compared to the existing systems, we see the strengths of the SAMS HIVE system in its modularity and expandability as well as the interaction of temperature, weight and acoustic data. We believe that this is an important requirement for the development of a reliable decision support system (DSS) and will continue to play a major role in the future. Furthermore, the popular platform (Raspberry Pi) is an ideal basis for bringing the project back to schools, universities, makerlabs and communities of science and research, thus generating a large community of interest. Due to the relatively large modular components, a reproduction with hobby tools is easy. Therefore no SMD components are used so far. The SAMS HIVE system already has the character of a marketable product. Long-term tests and software adaptations in terms of DIN ISO 9241-210 are still necessary. In addition, a solid data basis is still missing to use the full potential of the data warehouse. Therefore the expected target group of business start-ups will shrink for the time being and science, makerlabs as well as interested beekeepers who want to contribute to the further development will come into focus.

4.7 Optimisation and local adaptation

Adaptation of SAMS HIVE system

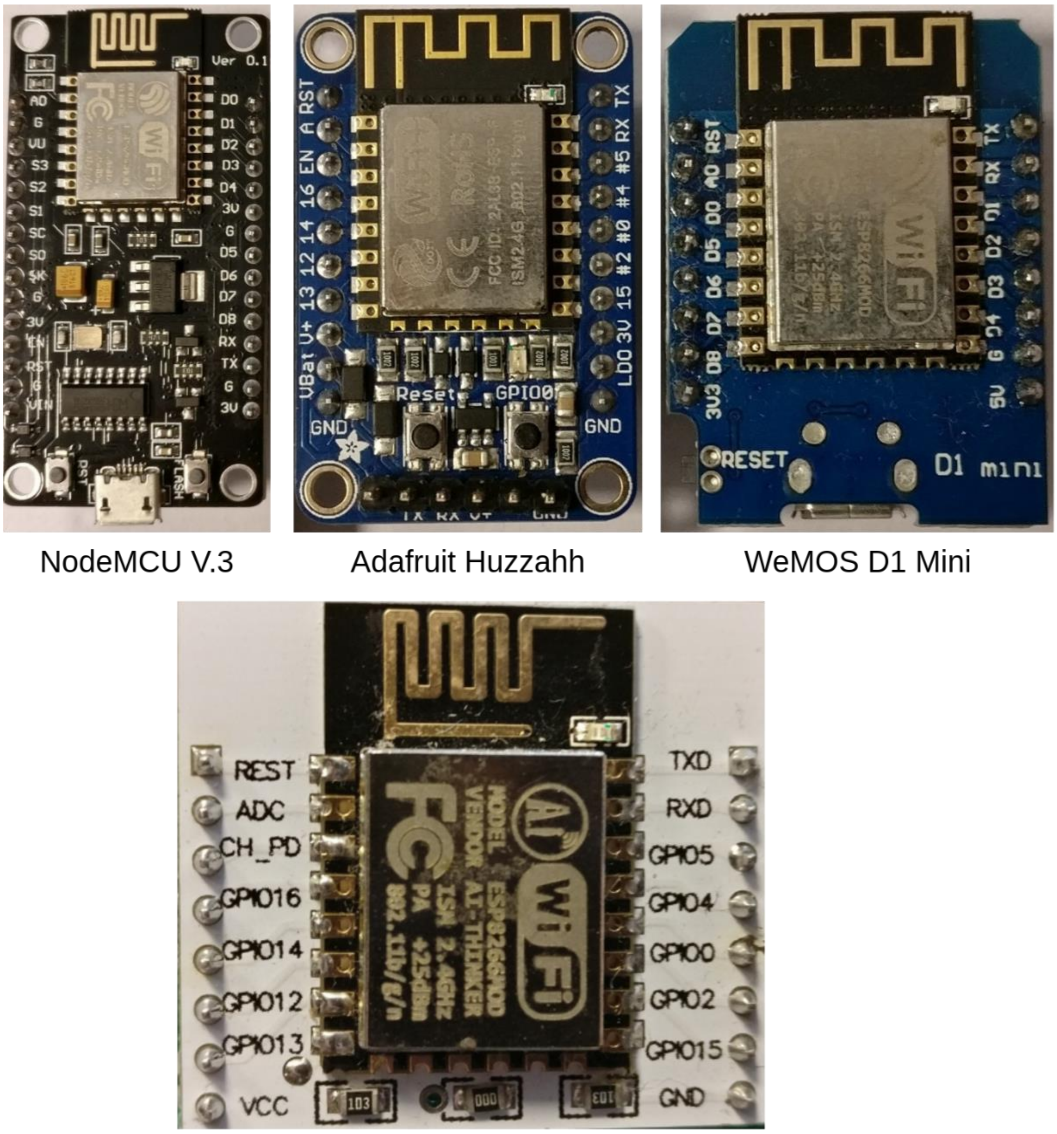
During the time the SAMS HIVE system based on Raspberry Pi was getting software improvements, the system was adapted to be used with the NodeMCU development platform that is based on ESP8266 microchip. Partners from LLU had previous experience with such microchip being used for monitoring purposes, and since most of the hardware parts are fully compatible with the microchip, it did not affect the implementation. To reach the goal to deliver as much data as possible from Apis Cerana hives, it was decided to run such a system in parallel while waiting for the improved Raspberry Pi software. This adaptation was also based on motivation to develop a more affordable, more energy efficient system from locally available components.

ESP8266 microchip based boards

The ESP8266 microchip (Figure 26) encompases TCP/IP stack with MCU (microcontroller) capability. Meaning, it is possible to program it, control input/ output signals and use WiFi capability - connect to a wireless network. This specific chip is a 32-bit MCU with a CPU that runs at 80MHz by default (can be set to 160MHz). As one of its purposes is to be used in IoT applications, ESP8266 design includes power-saving architecture that features three modes: active, sleep and deep sleep mode. Deep sleep mode is specifically useful when the microchip is battery-powered (https://www.espressif.com/en/products/socs/esp8266).

Figure 26: ESP8266 microchip

One of the most popular platforms that are based on ESP8266 in the market is called NodeMCU. This platform is just one variation of different platforms/ development boards that are based on the ESP8266 microchip (Figure 27), others, to name a few, are: WeMOS D1 Mini, Adafruit HUZZAH ESP8266 Breakout board, different NodeMCU variants (V.2, V.3). Besides these boards the ESP8266 microchip can be used together with an adapter plate that "breaks out" (gives access to) the microchip's GPIO (General Purpose Input/ Output) pins. These pins are used to read sensor data, attach other components (like buttons), actuators or modules (like analog to digital converters or SD card module). The number of available GPIOs depends on the manufactured platform.



NodeMCU V.3 Adafruit Huzzahh WeMOS D1 Mini

ESP8266 with adapter board

Figure 27: Different platforms based on ESP8266

There are some advantages and disadvantages when using some of the development platforms. The main advantage is that some platforms, like the NodeMCU and D1 Mini, do not require an additional device to upload/ flash the code or send output messages to the computer (usually needed during code debugging). There is a built in micro-USB port that eases the code flashing - the user just needs to plug the according USB cable and the device is ready to communicate with the computer. On the downside, these platforms are equipped with a lot of additional components (like voltage regulators, USB to serial chip) that are not always necessary to have to be able to operate this device. These components may increase power consumption and need to be taken into account, when used in battery powered applications.

Another option is to use the ESP8266 with an adapter board. In this case there are no additional components that could draw extra electrical current therefore it is more energy efficient in comparison with other development platforms. But the downside, when using the ESP8266 with adapter, is the need for a USB to UART (Universal Asynchronous Receiver/ Transmitter) converter in order to upload the code to the microchip.

Due to the features available within the ESP8266 (connectivity to a WiFi network, MCU capabilities) and their low price, these microchips are very affordable - in stores in Indonesia the price range is usually between 2 to 5 EUR.

Sensor setting for the adapted monitoring system

The overview of the ESP8266 microchip clearly shows that it can be used for monitoring purposes: to read the sensor data and transfer it wirelessly. Besides this, with ESP8266 as the core part, the whole monitoring system could be battery powered. Figure 28 shows the sensor and module compatibility of the system based on Raspberry Pi Zero W with an ESP8266 platform (the sensors and modules that are fully compatible, have been tested and can be used for bee colony monitoring are colored in green) and it can be concluded that all sensors and modules can be used, except the microphone, that has not been tested. And also during the SCM in Jelgava, the consortium agreed to focus mostly on temperature, humidity and weight monitoring.

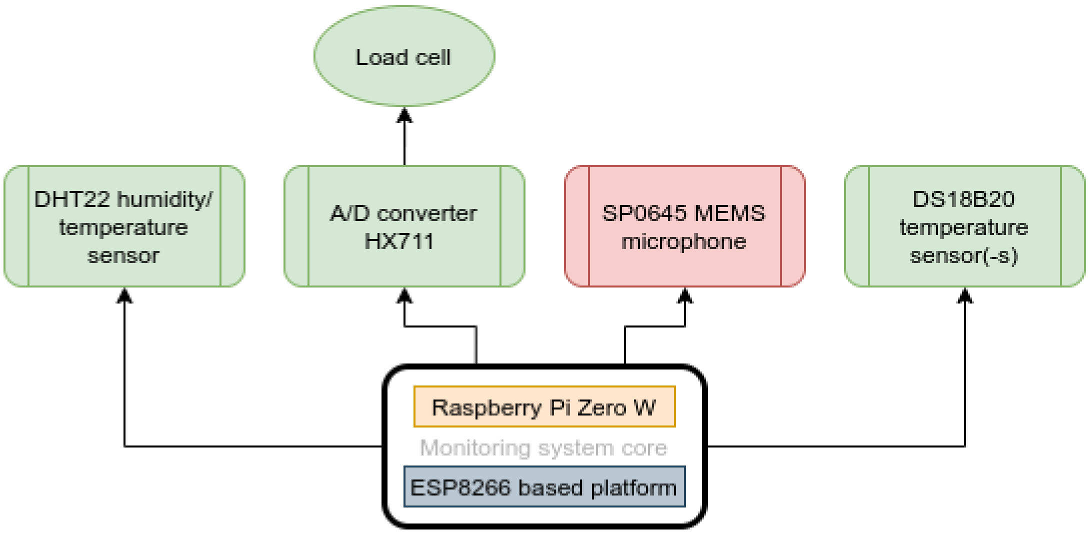


Figure 28: Sensor and module compatibility between ESP8266 based platform and Raspberry Pi Zero W

System prototype iteration steps

To test the operation of the system, in total 3 separate iteration steps were performed by the LLU team. During these testing stages, various ESP8266 based boards were used to make sure that the number of GPIOs is sufficient for all the popular variants. At first, to test the concept, all necessary components for low power operation together with the ESP8266 with adapter board was placed on a breadboard (Figure 29 (1)). Same test was also performed with

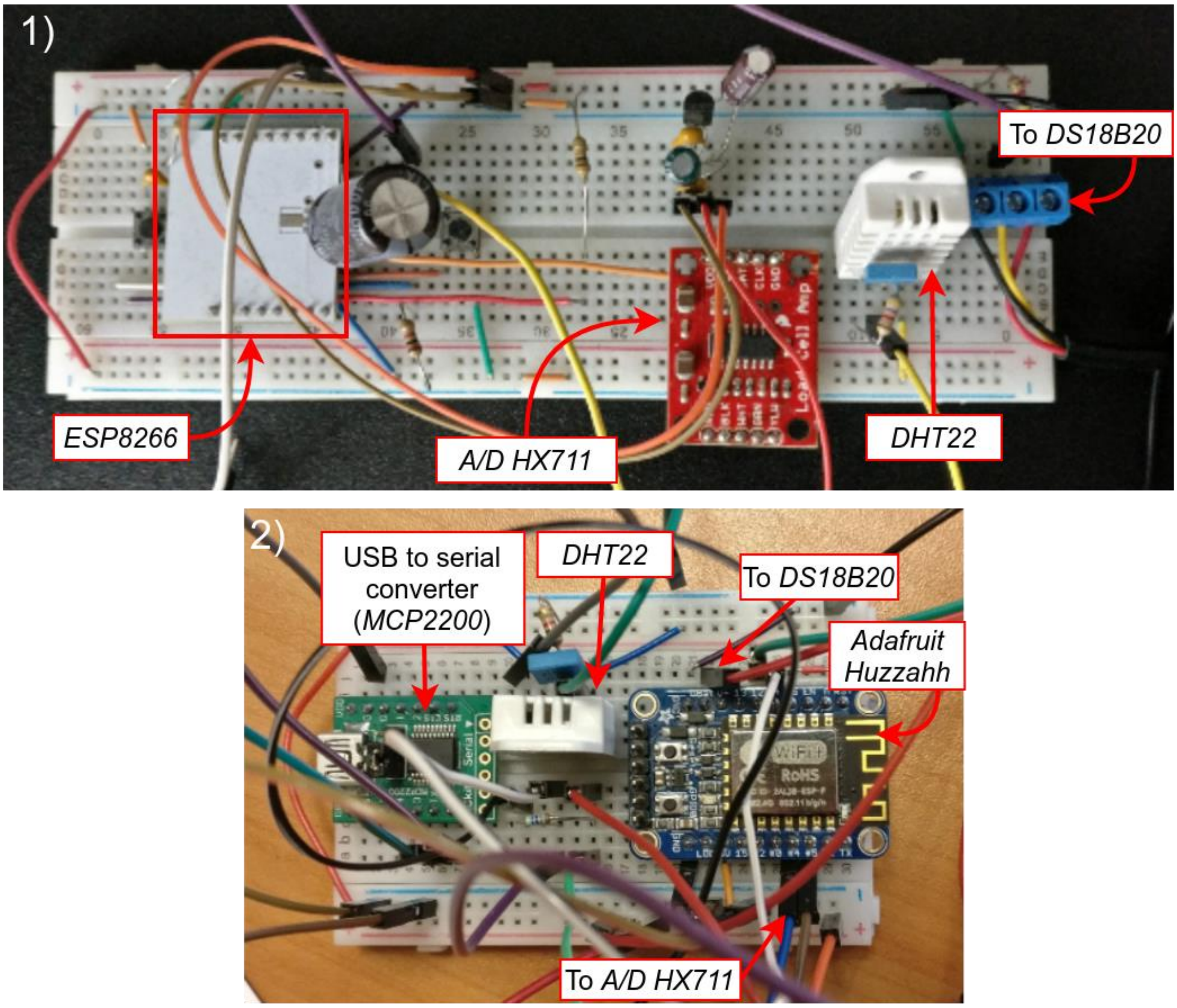


Figure 29: First prototype iteration step on breadboard: 1) with ESP8266 with adapter board; 2) with Adafruit Huzzahh

the Adafruit Huzzahh board (Figure 29 (2)). In parallel, partners from CV.PI also tested the NodeMCU and WeMOS D1 Mini platforms on breadboard.

After successful proof of concept, the system was soldered on a perfboard, so that modules and sensors could be pluggable making the monitoring system to be compact and portable. This was considered as the second iteration step (Figure 30).

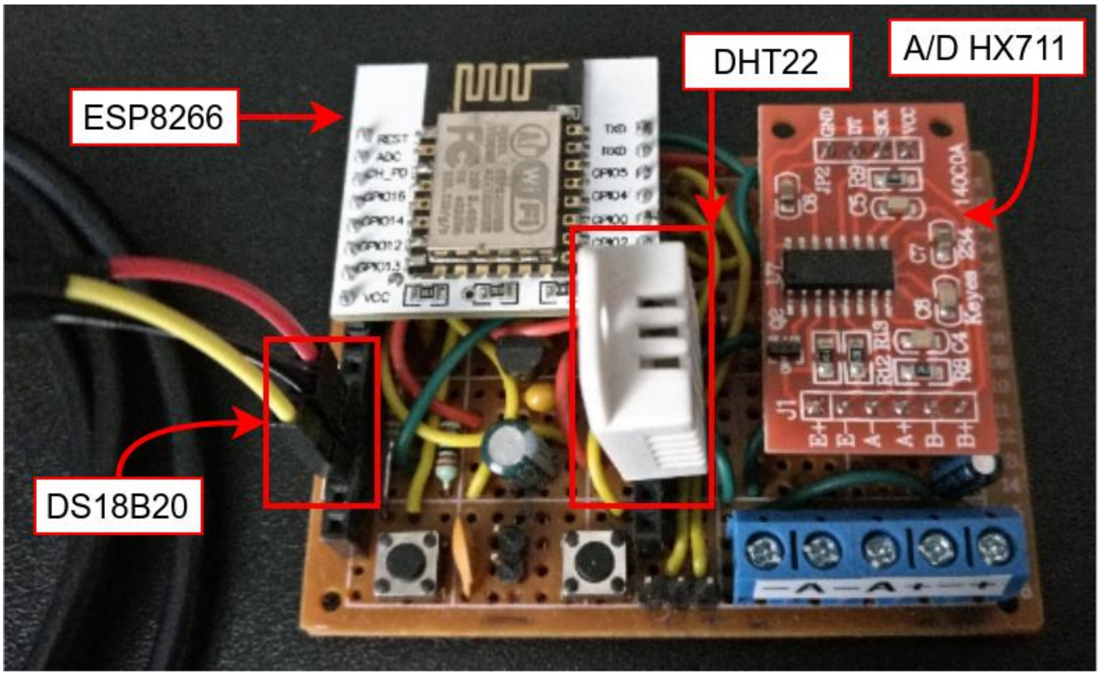


Figure 30: Second iteration of ESP8266 based monitoring system

The second iteration was also performed by the CV.PI team in Indonesia, where the parts were acquired and assembled locally. In total two systems were assembled: one with NodeMCU and the other with WeMOS D1 Mini board instead of the ESP8266 with adapter. The result of this iteration can be seen in Figure 31.

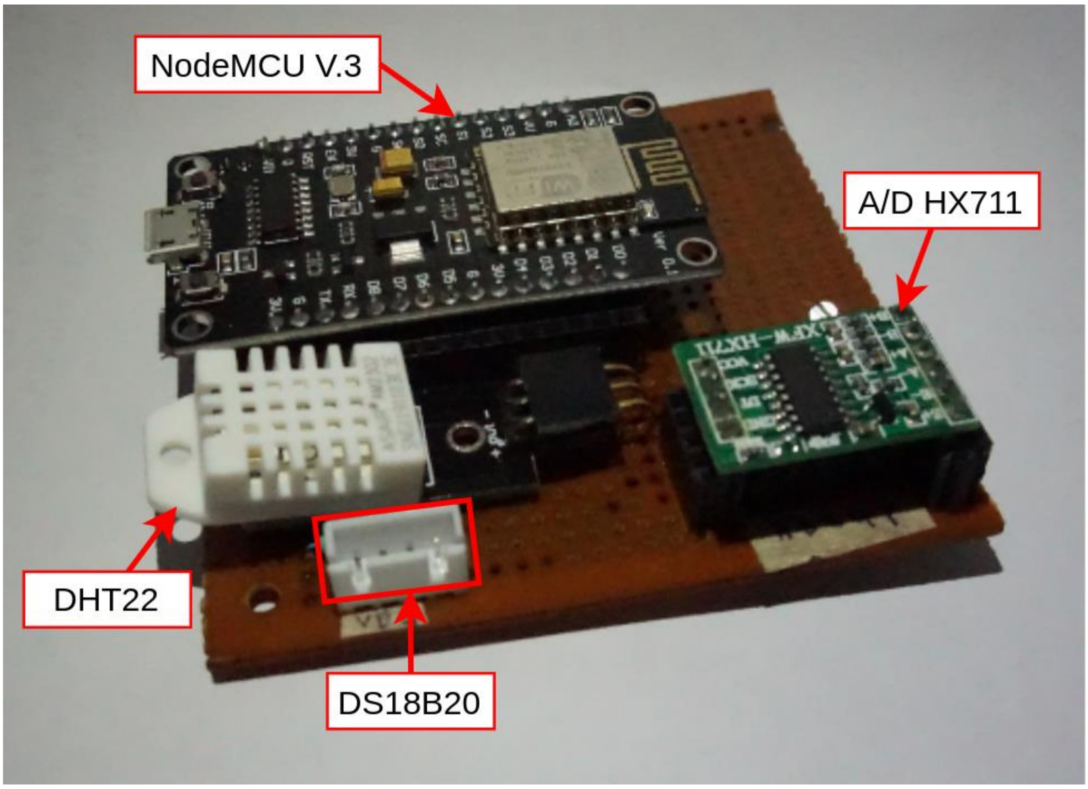


Figure 31: Second iteration with NodeMCU by CV.PI partners

To make the monitoring system more compact (smaller electronic components, remove wiring), easier to solder, assemble and visually appealable, a PCB was designed (Figure 32).

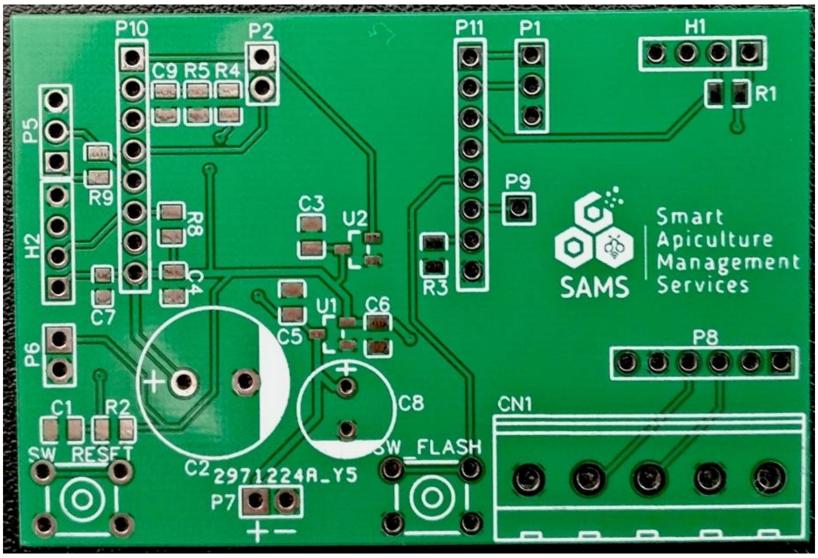


Figure 32: Developed PCB for ESP8266 based monitoring system

The fully soldered, assembled system is depicted in Figure 33 and is considered as the third prototype iteration.

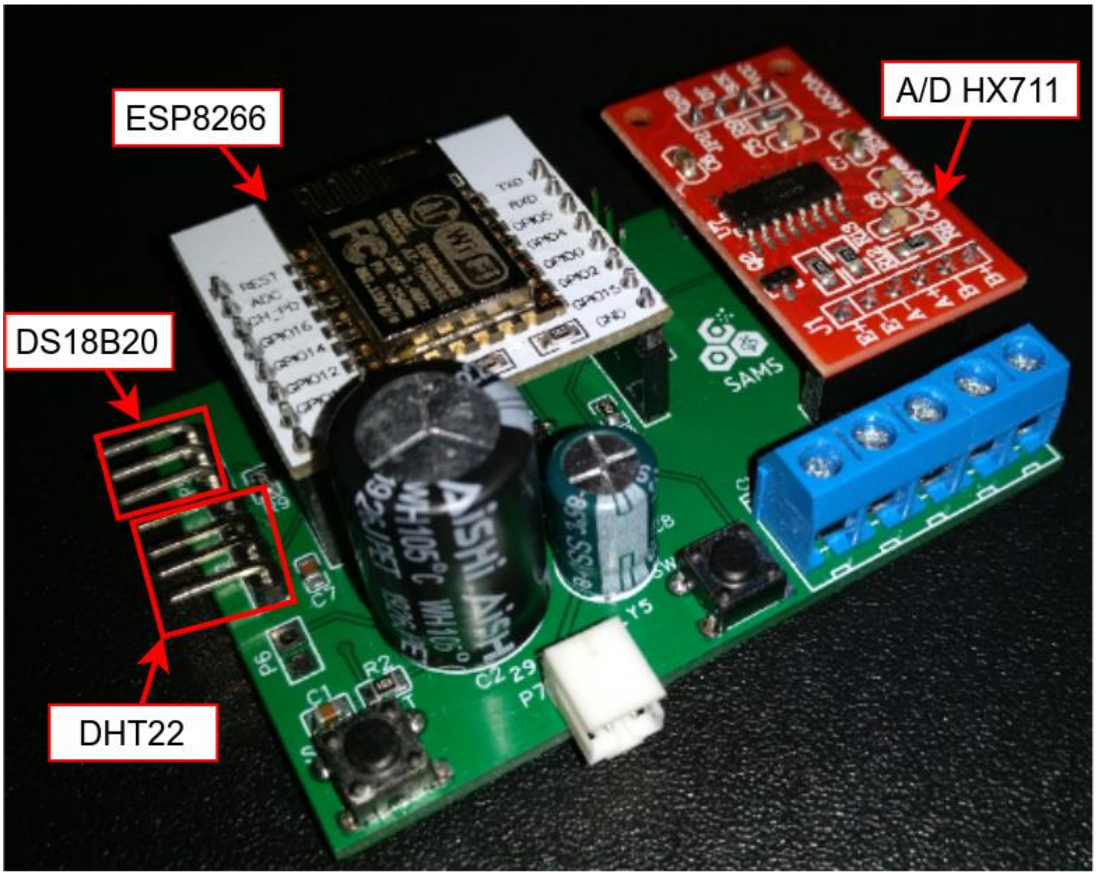


Figure 33: Third iteration of ESP8266 based monitoring system's prototype

Table 8 summarizes the component list of described ESP8266 based monitoring systems.

Table 8: Components list for ESP8266 based monitoring system

ESP8266 board			
#	Component/ module name	Type	Price (ID)
1.	ESP8266 with adapter board	WiFi microchip	~4EUR
	FTDI FT232rl or similar board like MCP2200	USB to serial converter adapter module	~2EUR
	PCB manufacturing	PCB	~2EUR (per board in large quantities from China manufacturers)
2.	NodeMCU v3	Development platform based on WiFi microchip	~3.5EUR
	Perfboard	Board to solder components	~2EUR
Sensors and modules			
1.	OKY3478-1	Load cell amplifier module; IC:HX711	1EUR
2.	DS18B20 digital thermometer	Temperature sensor	~2EUR
3.	DHT22 (AM2302)	Relative humidity and temperature sensor module	4EUR
4.	H30A	Load cell	50EUR
5.	**Other electronic parts*	*PCB headers, sockets, buttons, capacitors, resistors, voltage regulators, voltage supervisor ICs*	*~20EUR*

**Some of the parts, like resistors, capacitors, are sold in batches rather than individually. Therefore the total amount really is not per one system, but contains extra parts*

Sensor components and modules in total cost around 57EUR in Indonesia.

If the monitoring system uses NodeMCU, it adds 3.5EUR and additional 2EUR for perfboard to solder the components. In total, the system costs ~63EUR + extra costs for other electronic parts that usually are sold in batches and is hard to determine per one system. It is also worth mentioning that the most expensive component is the load cell (50EUR).

If the monitoring system uses ESP8266 with adapter board, it adds extra 4EUR and 2EUR for a device to upload the code (but this part is not necessary to be bought per ESP8266, but one is enough). Also to put these components together, a PCB is required, adding 2EUR more. Therefore, in this case the total costs are 65EUR + extra costs for other electronics parts. It should be mentioned these calculations does not include the scale assembling (metal plate, plywood etc.), 2G/ 3G WiFi router and SIM card.

Evaluation of power consumption

Since this monitoring system was intended to be powered by batteries, current draw was evaluated by distinguishing several operation states/ modes. Monitoring system based on ESP8266 with an adapter board was evaluated. In order to reduce the current consumption to the minimum, ESP8266 was put into deep sleep mode. This means that most of the modules of the microchip were turned off. In overall the main parts of ESP8266 infrastructure is shown in Figure 34.

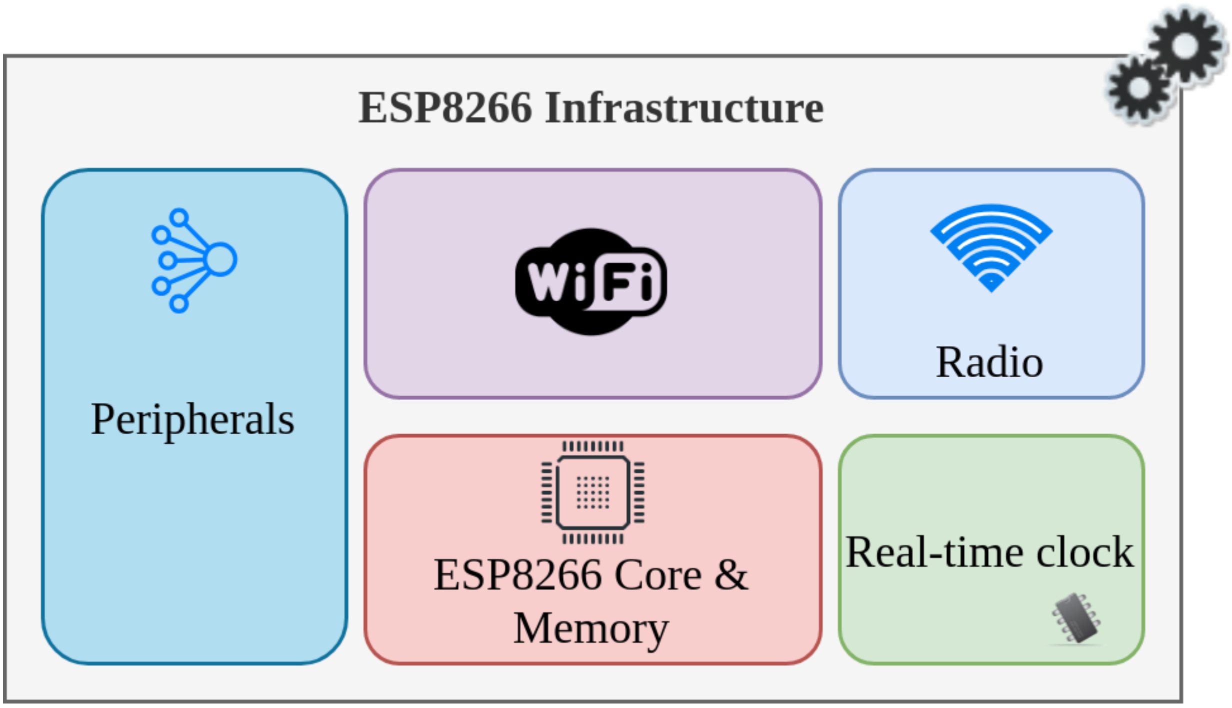


Figure 34: Main modules of ESP8266 microchip

By default, in normal operation all of these depicted features are on and consuming power. When the ESP8266 is put into deep sleep mode, only the RTC (real-time clock) is left operating and serves the purpose to “wake up” the microchip after a predefined time has elapsed. Another useful feature of the RTC is that it provides a certain amount of memory that can be used to store information. This is important, because, when the microchip goes into the deep sleep mode, all the information (values of the variables used in the program) that was put in the ESP8266 RAM (random access memory) is lost, meaning, when the microchip “wakes up” it reboots itself and the program starts from beginning by initializing all of the variables with default values. Therefore, the RTC’s memory allows to save states of some variables that are being modified during the ESP8266 operation time. The value of access token can be mentioned here as an important piece of information that needs to be stored during the ESP8266 wake ups, because this minimizes the number of requests needed to acquire the access token. Token should be requested again only when the access token’s expiration time is reached (not valid) or the ESP8266 is powered up for the first time. Only when the power of the microchip is completely off (e.g., battery removed), the RTC memory loses its information in it. The amount of available memory is not very large, according to the RTCVars library (for RTC memory management in ESP8266 microchips)(https://github.com/highno/rtcvars) 477bytes can be used to store information. Such an amount is enough to store access token.

The ESP8266 with an adapter board based monitoring system was set to measure temperature, humidity and weight every 60s. The evaluation of current consumption was performed by logging data with UNI-T UT181A True RMS Datalogging Multimeter. Current consumption per operational mode during one iteration of measurements is represented in Figure 35 and was as follows:

- Measurement mode (device is making measurements and getting values from connected sensors): 25mA for 1.2s;
- WiFi power-up mode (device is switching on the Wi-Fi module): 47mA for 1.4s;
- Connection mode (device is connecting to the Wi-Fi network and getting network configuration parameters): 69mA for 2.3s;
- Data sending mode (device sends measurement data): 79 mA for 1.8s;
- Going into sleep mode (switching off the modules): 36 mA for 1.4s;
- Sleep mode (there is no activity of the device, it is in a deep sleep state): 0,028 mA for 60s.

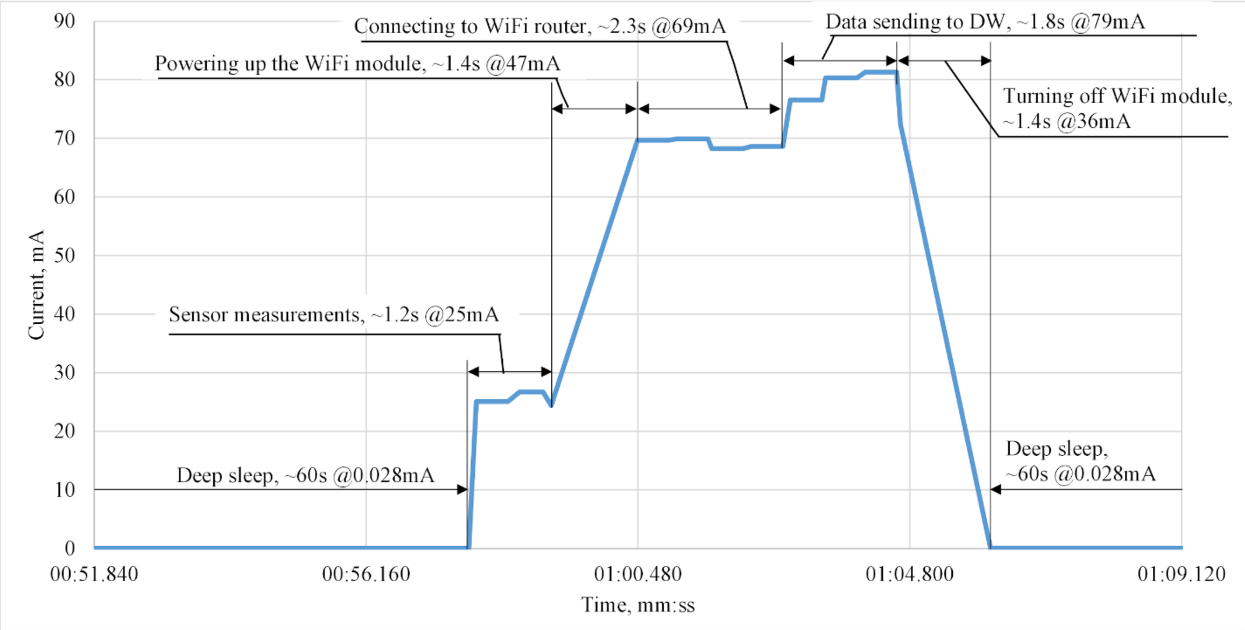


Figure 35: Current consumption during several operational modes in one iteration of measurements

Installation in apiary and first results

After the prototype iteration steps were completed and the performance testing was done, two monitoring systems (NodeMCU and D1 Mini based) were implemented (Figure 36) in Maribaya, Indonesia.

Figure 36: Implemented NodeMCU based monitoring system

Monitoring system was equipped with one scale for weight measurements, three DS18B20 temperature sensors to measure temperature in different places inside the hive, one DHT22 to measure ambient temperature and humidity. The placement of three DS18B20 proved to be a successful test, because it allowed to determine the optimal sensor position in order to get the temperature of the Apis Cerana bee colony. It was concluded that by placing the sensor in the middle, it is possible to obtain the desired temperature values, which do not change with the influence of the external temperature Figure 37.

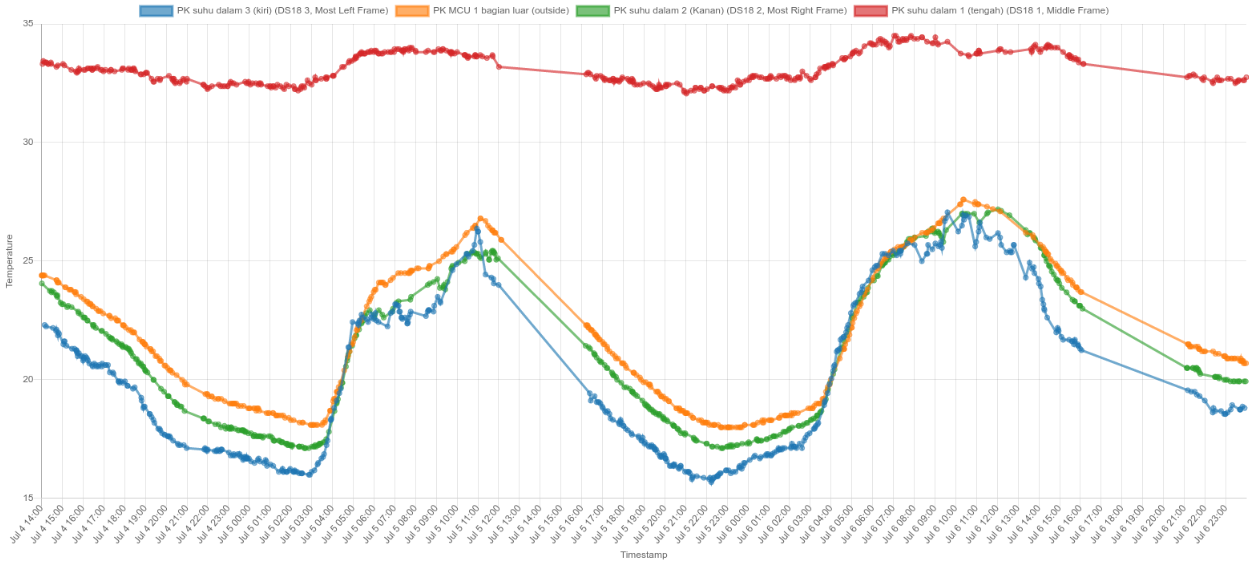


Figure 37: Temperature values inside the hive: red curve - temperature in the middle frame, orange curve - ambient temperature, green curve - temperature in the most right frame, blue curve - temperature in the most left frame

Further improvements

During the various iterations and testing, it was observed that there were interruptions related to data transfer and connection to the WiFi router. Also distance, the WiFi router can cover, plays a significant role - in Indonesia the hives are placed with large distances between them. This led to a consideration to make the monitoring systems WiFi router independent and use a GSM/GPRS module/ modem to directly connect to a mobile network. One such module is the very cost-effective SIM800L, which is priced at ~3EUR in Indonesian electronics stores. This module is also more power efficient when compared to WiFi routers and can be put in a sleep mode as well, during which it consumes around 1mA.

4.8 Target rating

Table 9 evaluates the success of the implementation to meet the main objectives stated in Chapter 1.1, which are based on basic requirements and the main criteria derived from the beekeepers needs, based on the UCD process in work package 2. The evaluation is based on the classification of high, middle and low target achievement. More than half of the goals have already been achieved, while 40% depend on other factors, such as the continued collection of data as a basis for a DSS. One goal could not be achieved.

Table 9: Evaluation of target achievement

Target	Rating			Comment
	high	middle	low	Evaluation of target achievement

Power grid independent, for location-independent installation				
Cost-effective, in order to enable smaller beekeepers to obtain financing as well				Compared to market prices in the medium range
To reproduce with simple means in order to be able to reach a broad target group				Depending on local availability
Open source, for easy access and further development in the community				
Expandable by further measurement parameters (e.g. weather station, camera) to cover a wide range of sensor options				
Transferable to common hive sizes, for easy installation				
Wireless data transmission, for rapid availability for the end user and researchers				
Low data volume, for fast and cost-effective data transfer				Depending on the function. Acoustic data require more volume
High stability, enabling low maintenance and long-lasting data collection				
Sustainability: Components and construction which are modular and easy to recycle				
Bee colony should be free from pests attack (wasps, ants, rats etc)				Depending on further data basis for DSS
Bee colony should be safe from thief				Not possible
Beekeeper should get support and coaching				Depends on further App infrastructure
New technology or methods should boost the productivity				Time saving through control reduction possible; Planning of harvest time
Bee colony should to be free from any disease				Depending on further data basis for DSS
System should help to take an appropriate action				Depending on the issue
System should help to know how much honey is allowed to be harvested in a colony				

Beekeeper should know if the colony is safe enough to be checked or not				Depending on further data basis for DSS
Beekeeper wants to know if there is an upcoming swarm in the colony				Depending on further data basis for DSS
Beekeeper wants to know the strength of the bee colony				Depending on further data basis for DSS
Total	**55**	**40**	**5**	**%**

Project website: www.sams-project.eu

Project Coordinator contact:

Stefanie Schädlich
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
Wielinger Straße 52
82340 Feldafing, Germany
stefanie.schaedlich@giz.de

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