International Partnership on Innovation

SAMS - Smart Apiculture Management Services

Deliverable N°3.3

High-fidelity HIVE Prototype Design Report

Work package 3 HIVE System

Horizon 2020 (H2020-ICT-39-2017)

Project N°780755

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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

SAMS consortium partners

Logo	Partner name	Short	Country
	Deutsche Gesellschaft für internationale Zusammen-arbeit (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
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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.

Three continents - three scenarios

(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 behavioural response
- Implementation SAMS Business cooperation

Content

List figures

List of tables

1. Background

The University of Kassel develops the HIVE measurement system (HIVE) within the SAMS project. The HIVE measurement system is a central part of the project and collects and pre-processes beehive data in our partner countries Indonesia (responsible partner UNPAD), Ethiopia (responsible partner HOLETA), and Germany (responsible partner UNIKAS). The collected sensor data is sent via Wi-Fi/internet to the project partner Latvia University of Life Sciences and Technologies (UNILV) for storage and further processing. Finally, the evaluated data will be used to support local beekeepers with e.g. information about health status, productivity and upcoming work on their beehives via a smartphone application or SMS.

1.1 Scope of the Deliverable

The report describes the development, commissioning, and improvement of the second prototype (hi-fi) HIVE measurement system including control software compared to earlier versions.

1.2 Development and Enhancments

The development from the first function model of the SAMS HIVE Monitoring System to the current prototype shows substantial improvements. Resource efficiency and sustainability are key criteria in our development. The current hi-fi prototype contains more sensors and consumes less power. This is achieved by using more energy efficient components. Overall, the acquisition costs are lower, as one photovoltaic system can power multiple monitoring systems. In addition, high-quality components were used to ensure a long and reliable lifecycle.

An extra cooling system could be dispensed with as more heat-tolerant components were used. In order to make work easier for the user during installation, a low weight of the system was taken into account by exchanging the casing and replacement of the sensors. This could also has advantages for the bees as there is less Wi-Fi radiation directly in the brood nest. The plug connections of the cables to the power supply and to the sensors provide an easy assembling and disassembling.

Programming of the software was done with simple processes and low susceptibility to errors to create a robust system. Should errors still occur, for example due to incorrectly connected cables, these can now be checked online in the extensive log files of the devices.

2. Technical Construction

The following chapter explains the technical design and development of the hi-fi HIVE Monitoring System. The system contains several functional groups:

1. The power supply with router to run up to 10 monitoring units.
2. The central computer unit where the sensors are connected.
3. The sensor frame with temperature sensor and microphone placed in the beehive.
4. The scale unit placed beneath the beehive with outdoor temperature and humidity sensor.

Function groups and the components are described in more detail. The sensor placement, the housing and the cable connections are also shown. In addition, the software is explained and cost calculations are presented.

2.1 Function Principles

The power supply for the Monitoring Units is provided by a photovoltaic system (Power unit) via cables. It consists of the standard components: solar module, charging controller and battery. The dimensioning depends on the location, the number of monitoring units and the measuring intervals. Our proposed configuration of power unit is designed for up to ten monitoring units under comparably low solar radiation (Chapter 2.2). The power unit also supplies a mobile GSM Wi-Fi router which is used as a hotspot for the monitoring units to transfer data to a web server (SAMS Data Warehouse) (Figure 1). The power unit should be installed centrally to reduce cable distance and to ensure the Wi-Fi radio signal. However, the power supply cable is the only cable between the monitoring units. In order to avoid cables, the power supply could also be provided by a power bank, but should not be used for reasons of sustainability and maintenance. An alternative is to install a mini photovoltaic system on the beehives for each monitoring unit. Nevertheless, this would increase the costs and the installation effort.

The monitoring unit consists of a printed circuit board (PCB) with Raspberry Pi single board computer, a step-down converter to change the voltage of the power unit to 5V, and a 24-bit analog-to-digital converter (ADC) that converts the Wheatstone bridge signals of the load cell to a digital format. The sensor frame with temperature sensor and microphone are also connected to this unit. This allows the acoustic signals and the temperature in the colony to be recorded.

In addition, a scale can be connected to the computer to measure the weight of the colony. The computer can easily be extended with additional sensors. For example, it is possible to connect a small weather station to collect region-specific climate data. It is also possible to connect several temperature sensors. Thus either an exact recording of the local temperature gradients in the brood nest can be done or one monitoring unit can record the temperature of several beehives in the radius up to 70 meters. This could be of particular interest for the breeding of bees for Varroa mite resistance in order to precisely analyse the breeding behaviour.

The computer can be put into deep sleep between the measuring intervals by means of a power control unit (WittyPi) in order to reduce energy consumption considerably. As soon as the computer receives power from the power unit, it starts the measuring routine. The measuring routine and the interval can be adjusted as required. A permanent measurement is possible but is not considered useful to reduce energy and therefore costs of the photovoltaic system. After successful recording, the data is transferred via Wi-Fi to the mobile GSM router and sent to the web server (Figure 1 and 2).

Currently 6 measurements per day are set as standard. An average value from seven measurements is transmitted for temperature, humidity and weight. The acoustics in the bee colony are recorded over 180 seconds and uploaded as Fast Fourier Transformed (FFT) spectrum. It is recorded with 16 kHz sampling frequency, covering a frequency range from 0 kHz to 8 kHz. The FFT is made with 4096 points resulting in a frequency resolution of approx. 3.9 Hz.

If there is permanent power supply, the default interval is 900 seconds, i.e. a new measurement with all available sensors is carried out and uploaded approx. every 18 minutes. If a file has been successfully sent, the computer waits another 900 seconds (if no restart has taken place in between) until the next measurement. If the upload is not possible, the data remains on the SD card until a successful upload has been performed. In this case, a new upload attempt starts after 30 seconds. Each device has its own ID so that it can be uniquely assigned on the web server. Individual sensors can also be added or mapped to users, locations or groups on the web server. Successful recording, data storage, uploads or errors are logged and also transferred to the web server. Events for troubleshooting can be viewed there by administrators. On the device, 2 LEDs indicate working or deep sleep mode. Plug connections ensure easy installation. The sensor frame is connected via a 9-pin D-Sub connector (known as VGA) and a standard DC power plug was selected for the power supply.

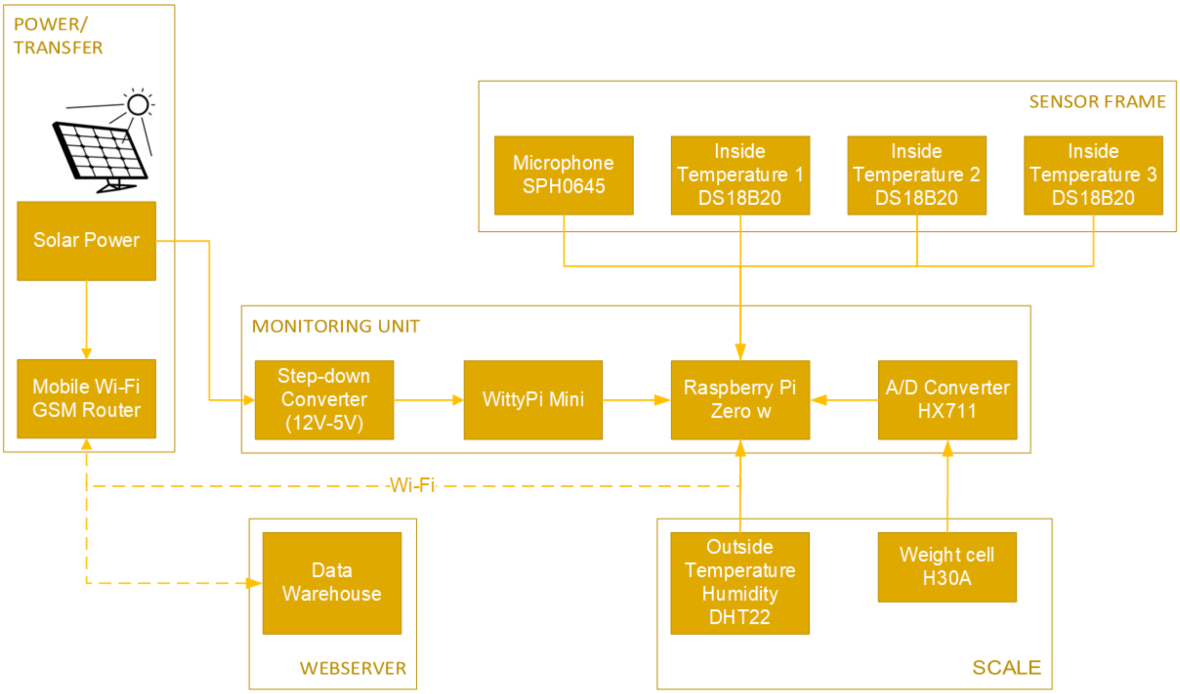


Figure 1: Flow chart of the SAMS HIVE System with Power unit, Scale unit and Sensor frame

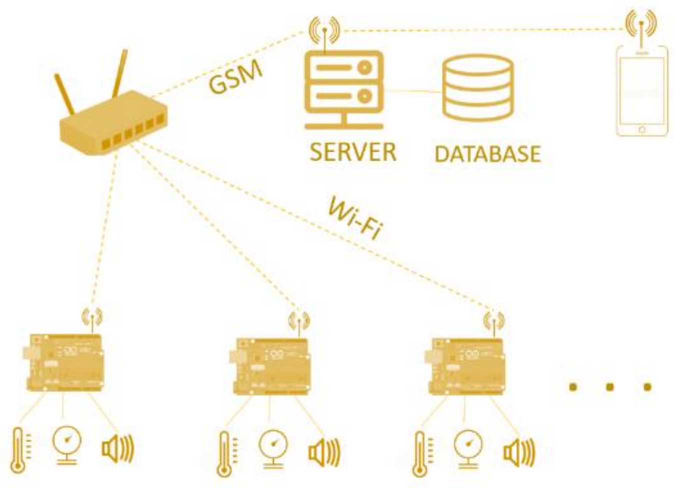


Figure 2: Connection sketch of internet-compatible devices

2.2 Components for Solar Power

For dimensioning the photovoltaic system, a theoretical daily global horizontal irradiation of 4 kWh/m²/d on average was assumed. This is based on the lower average values of the solar resource map published by the World Bank Group for the global horizontal irradiation of our project partner countries Indonesia and Ethiopia (Figure 6, Figure 7 and Table 3).

With a consumption per monitoring unit of 70 mA and 700 mA for the GSM router, 50 measurement intervals of 5 minutes each can be recorded with the current design for ten operating monitoring units. A doubled power of the photovoltaic system is easily possible and would allow a permanent measurement throughout the day. For the current scientific configuration, it is ideally designed and offers large safety buffers. As shown in Table 1 and Table 2, the total consumption is less than 3 Ah per day. However the photovoltaic system provides at least 10 Ah per day (Table 4). The demand is therefore sufficiently covered.

Figure 3: Solar modul Phaesun Sund Plus 50 S (conrad.de)

A monocrystalline 12 Volt Phaesun Sun Plus 50 S solar module with 50 Wp output was selected as solar module (Figure 3). A 10 A PWM Phocos eco 10 charge controller was installed between the battery and the solar module (Figure 4). A standard car battery (100 Ah) is needed as accumulator. Figure 5 shows the power unit with solar module, charge controller and battery in a water-protected timber box.

Figure 4: Phocos eco 10

As shown in Table 5, the cost of the photovoltaic system is around 200 €. If fewer monitoring units are needed, the system can be adapted and the costs reduced.

Table 1: Measurement Length of Sensor Data

	Length of Measurement Interval [s]
Sound (FFT)	180
Temperature (Median)	1
Weight (Median)	1
Humidity (Median)	1
Measurement Pause	3
Upload	60
Upload Pause	900
Retry Pause (2x)	30
Total	1200

Figure 5: Solar Power System (Holeta, 10.04.2019)

Table 2: Power Consumption

Consumer	Amount of Measure ments per Day	Amount of MU	Length of Measure ment [h]	Total Consumption per Day [h]	Power Consumption per Device [mA]	Total Consumption [Ah]
Monitoring Unit (MU)	6	10	0,3	18	70	1,26
Mobile GSM Router	6	1	0,3	1,8	700	1,26
					Total	**2,52**

Table 3: 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

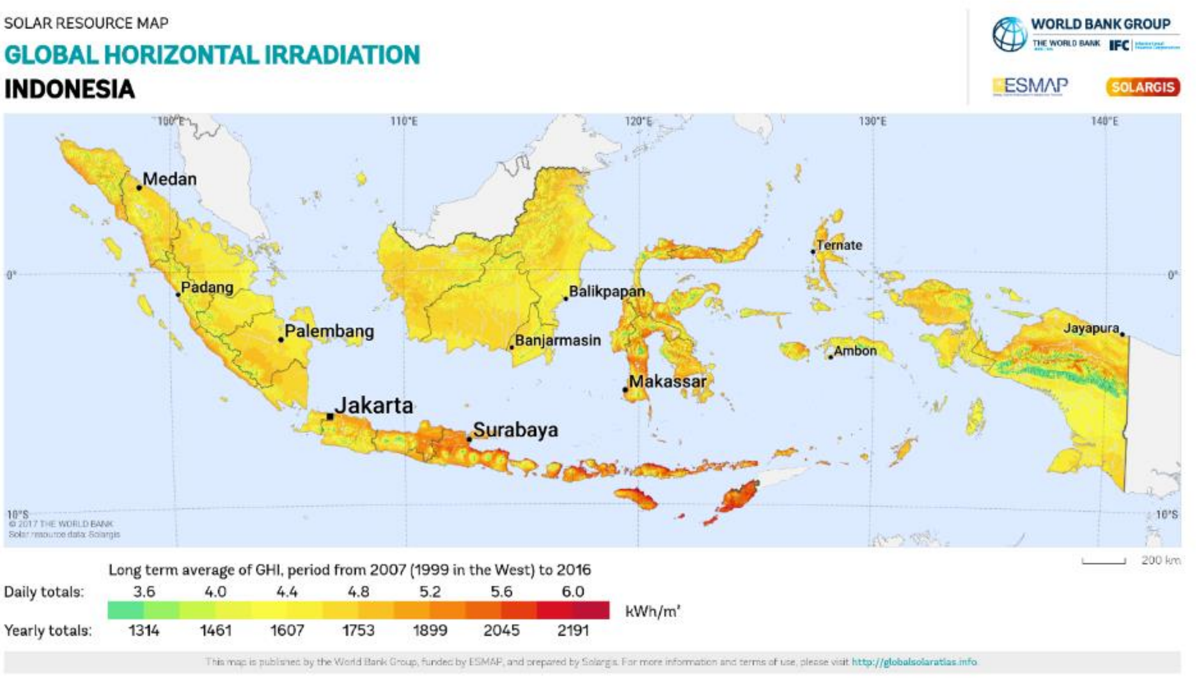


Figure 6: Global horizontal irradiation in Indonesia (globalsolaratlas.info)

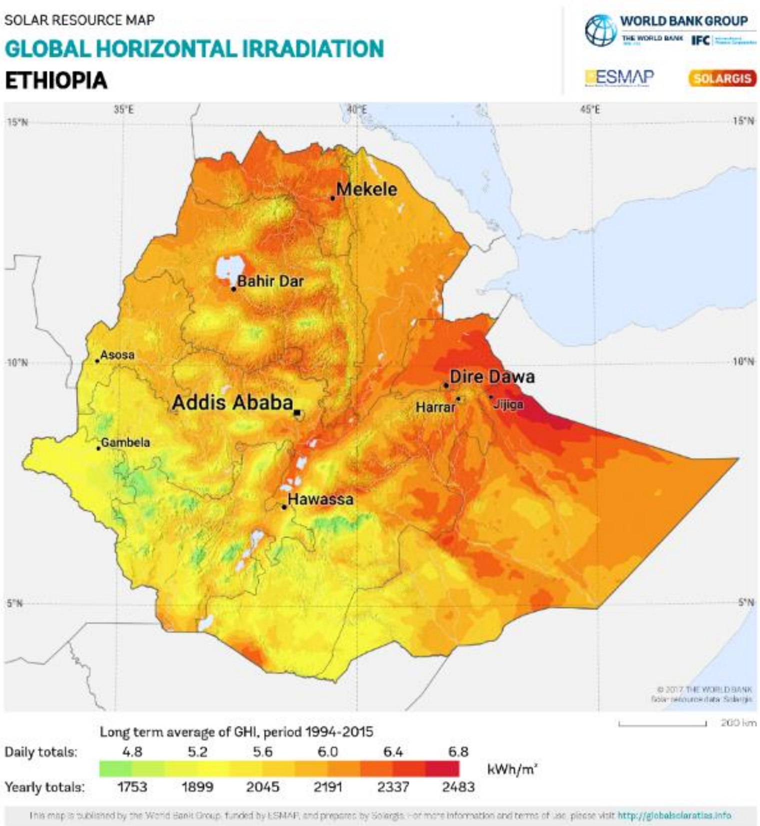


Figure 7: Global horizontal irradiation in Ethiopia (globalsolaratlas.info)

Table 4: Solar power calculation

	Jan	Feb	Mrc	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Average daily global horizontal irradiation											
Theoretical assumed value from average	4	4	4	4	4	4	4	4	4	4	4	4
(see globalsolaratlas.info)	4,00											
with solar generator power	50 Wp											
Theoretical daily energy yield	200 Wh/d	200 Wh/d	200 Wh/d	200 Wh/d	200 Wh/d	200 Wh/d	200 Wh/d	200 Wh/d	200 Wh/d	200 Wh/d	200 Wh/d	200 Wh/d
radiation area Average total	17 Ah/d	17 Ah/d	17 Ah/d	17 Ah/d	17 Ah/d	17 Ah/d	17 Ah/d	17 Ah/d	17 Ah/d	17 Ah/d	17 Ah/d	17 Ah/d
Temperature correction factor [Ft]	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Factor for cable losses [Vk]	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Factor for conversion losses [Vu]	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
Factor adjustment losses [Va]	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
Correction factor [Ft*Vk*Vu*Va*Fw]	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81
Corrected, daily usable energy	162 Wh/d	162 Wh/d	162 Wh/d	162 Wh/d	162 Wh/d	162 Wh/d	162 Wh/d	162 Wh/d	162 Wh/d	162 Wh/d	162 Wh/d	162 Wh/d
radiation area average total	13,5	13,5	13,5	13,5	13,5	13,5	13,5	13,5	13,5	13,5	13,5	13,5
Input: Average daily consumption [Ah]	10,0	10,0	10,0	10,0	10,0	10,0	10,0	10,0	10,0	10,0	10,0	10,0
Input: Battery capacity	100 Ah											
Solar generator power	50 Wp											
Energy Balance	autark	autark	autark	autark	autark	autark	autark	autark	autark	autark	autark	autark
Capacity until 50% unloading depth is reached -with solar power-	autark	autark	autark	autark	autark	autark	autark	autark	autark	autark	autark	autark
Capacity until 50% unloading depth is reached -without solar power-	5,0 days	5,0 days	5,0 days	5,0 days	5,0 days	5,0 days	5,0 days	5,0 days	5,0 days	5,0 days	5,0 days	5,0 days

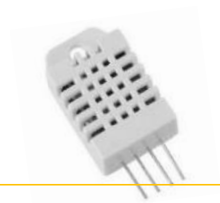
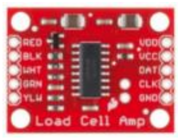
Table 5: Cost calculation for Solar Power System

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 €**

2.3 Components for Monitoring System

The following table 6 lists the components of the hi-fi HIVE Monitoring System including the single board computer unit.

Table 6: Components of the hi-fi HIVE Monitoring System

Component	Function	Specification	Photo
RaspberryPi 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 WittyPi mini+ 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	Outdoor 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 photovoltaic system	Output voltage is adjustable between 1.0 - 17V	

A mobile GSM Wi-Fi router type E5330 from HUAWEI is used to send the data to the Internet. Data sheets or links for all sensors and the Raspberry Pi can be found in the appendix. As shown in Table 7, the costs for the construction of the monitoring system are about 170 €. The costs of the router are not included here, as one router can be used by up to 10 monitoring systems and thus the costs are shared. Details on the case and the scale design can be found in later chapters. For the placement and connection of the components a PCB was made which is described in the following chapter.

Pos	**Name**	**Decription**	**Spec**		**Qty**	**Price per Item (in Euro)**
			Brand	**Type**		
1	RasperryPi Zero	Single-Board-Computer	Raspberry Pi Foundation	Zero W	1	16 €
2	WittyPi	Powermanagement	UUGear	WittyPi Mini	1	15 €
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	6 €
6	Load cell	Weight measurement	BOSCHE	H30A (150kg)	1	50 €
7	Header Pin	Socket connection		1x40 pin - Long	2	2 €
8	Platine PCB		chapter 2.4	2 Layer	1	15 €
9	Case				2	5 €
10	Aluminium plate large	Plate for Scale		150x100x10 mm	2	4 €
11	Aluminium plate small	Plate for Scale		35x35x6 mm	2	3 €
12	Mobile GSM Wi-Fi Router	Uploading Data via GSM	HUAWEI	E5330	1	30 €
13	Other small components	Screws, glue, etc.			1	5 €
14		Port D-Sub9 Female, DC to DC Conv, Spacer, Resistor, Socket Raspi, Jack D-Sub9 Male			1	15 €
15		Spacer, Cable, Port Input & Output,			1	25 €
					Total	**170 €**

Table 7: Cost calculation for SAMS HIVE hi-fi Prototyp

2.4 Circuit Layout

An electronic circuit diagram was developed for prototyping. The circuit diagram serves to connect the sensors and components with the Raspberry Pi. It is the basis to operate the Raspberry Pi with the programmed software as a monitoring system. The circuit diagram was drawn with the open-source software Fritzing and serves as the basis for the layout of the Printed Circuit Board (PCB) (Figure 8). The components are placed on a so-called breadboard, with vertical and horizontally connected traces, and connected accordingly (http://wiring.org.co/learning/tutorials/breadboard/). The breadbooard on Figure 9 contains Raspberry Pi (green), microphone (blue), temperature sensor (black), humidity sensor (white) and A/D converter (red). In addition a resistor (4,7kΩ) is installed between VCC and DAT pin of the DS18B20 (datasheet DS18B20). Microphone and temperature sensor are connected via the I²S interface of the Raspberry Pi. This makes it possible to connect several temperature sensors to the same port. If required, additional sensors like a brightness sensor, could be connected during this experimental phase and the software adapted accordingly. In order to be able to make changes during this phase and to involve the project partners in the development for feedback, the configuration was tested on the breadboard in the project partner countries Indonesia and Ethiopia.

After adapting the configuration to the needs of the project partners, the electronic circuit diagram was transferred to a PCB (Figure 10) for further testing. This reduced space requirements and simplified construction, as components were given fixed connections. The susceptibility to errors could also be reduced in this way. PCB soldering points for a screw terminal block were provided to allow fast connection without soldering work and to exchange components in the second prototype phase. The first version of the PCB contained a slot for the microphone. The monitoring system has to fit into a brood frame of the beehive. This configuration was changed in the course of development. The sensor placement is now separated from the computer. This reduces the Wi-Fi radiation in the colony and noise from hardware like step-down converter is avoided. It will be discussed in detail in the chapter Sensor placement.

The PCB layout can be downloaded as a Gerber file on Github under the following link: https://github.com/sams-project.

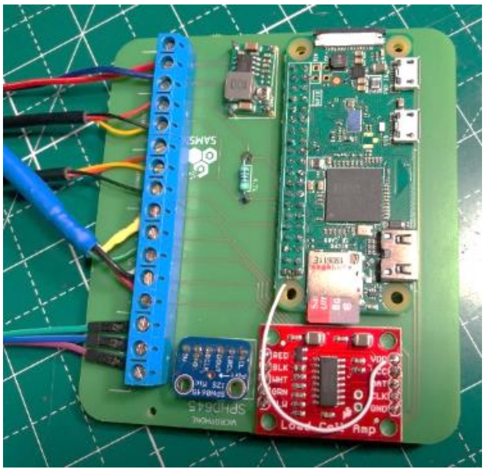


Figure 8: Circuit board with soldered components (first PCB version, with microphone on board)

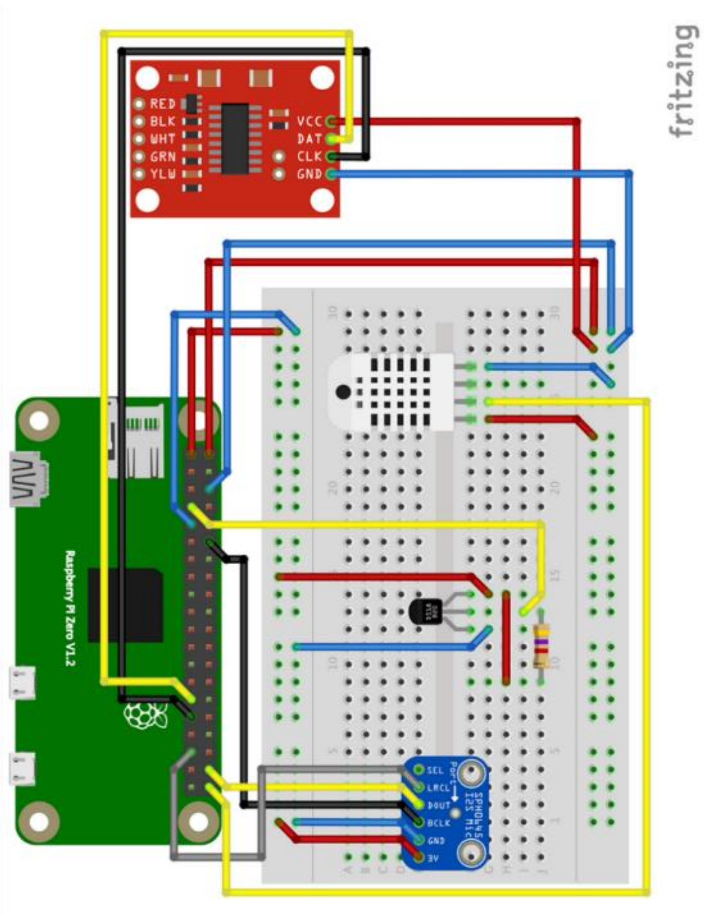


Figure 9: Fritzing bread board circuit

Raspberry Pi Wiring

<u>A/D Converter HX711</u>
VCC to 5V
DAT to Pin29/ GPIO 5
CLK to Pin31/ GPIO 6
GND to GND

<u>Microphone SPH0645</u>
LRCL to Pin35/ GPIO 19
DOUT to Pin38/ GPIO 20
BCLK to Pin12/ GPIO 18
GND to GND
3V to 3V

<u>Temperature DS18B20</u>
VDD to 3V
DAT to Pin7/ GPIO 4
GND to GND
(4,7kΩ VDD und DAT)

<u>Humidity DHT22</u>
VDD to 5V
DAT to Pin40/ GPIO 21
GND to GND

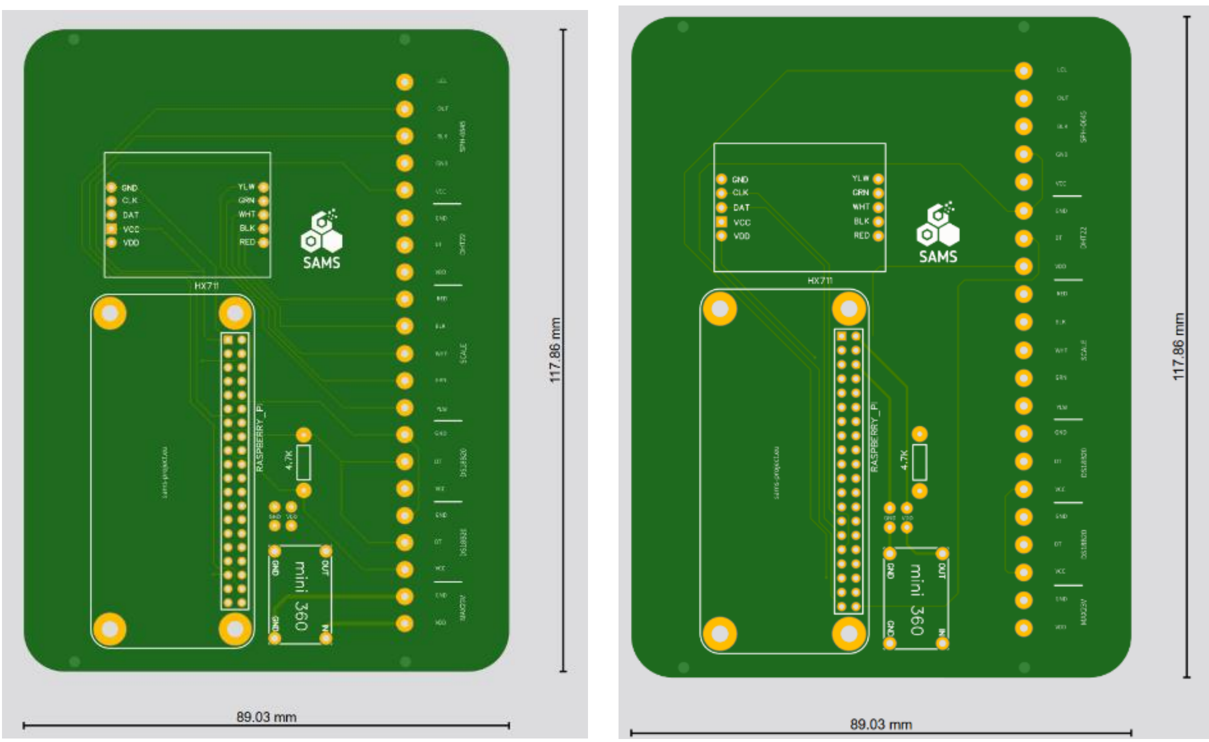


Figure 10: Top and bottom view of a ready to print circuit layout for the SAMS HIVE Monitoring System

2.5 Software

A software was developed to operate the Raspberry Pi and its components as a monitoring system. In order to ensure the simple and long-term availability of the code, a separate SAMS page was created on the Github developer platform. The code can be found open source at https://github.com/sams-project. Alternately, the software can be downloaded as Raspberry Pi Image from the SAMS project website https://sams.science.itf.llu.lv/images/prod4-wittypi.zip. The Raspberry Pi image can be installed directly onto a common MICRO-SD memory card. The memory card can be plugged into the Raspberry Pi and the system can be used. The SAMS Github page contains the code to operate the monitoring system and a web application to calibrate the functions. With the Web App, for instance, possible errors such as incorrectly connected sensors can be quickly identified. Figure 11 shows the SAMS Github page for the monitoring system.

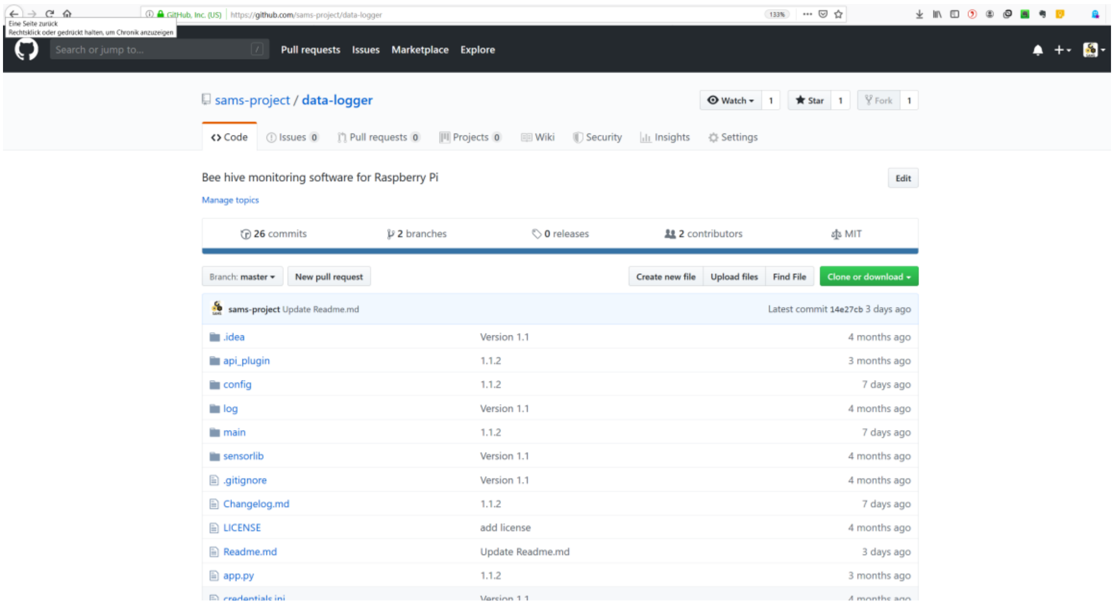


Figure 11: Screenshot Github SAMS Account - Bee hive monitoring software for Raspberry Pi (https://github.com/sams-project/data-logger)

The web application is based on Flask (https://palletsprojects.com/p/flask/), a web application framework and was specially adapted to the needs of the data logger for the SAMS project. It includes an internal API (application programming interface) which displays the data of the sensors in JSON format. The main purpose of this application is to simplify the calibration of the scale using a user-friendly interface. A special SCSS framework from anderswodenker (https://www.anderswodenker.de) was used for the styling of the individual pages. The little JavaScript was implemented with Vue (https://vuejs.org). Starting the web server on the Raspberry Pi is done by "supervisor" (https://github.com/AiGreek/Raspberry-Scripts/wiki/Supervisor) which starts a WSGI script and hosts the application under its own IP address when the Raspberry Pi is started. This supervisor also ensures that the data logger is started after the calibration of the scale and also restarted in the event of an error. The sensor library was taken from the data logger and is based on "minipi" (https://github.com/anderswodenker/minipi) a Python framework to access various sensors of the Raspberry Pi quickly and easily. In addition, this application has a rudimentary function to read out certain error data and thus provide assistance in finding sensor errors. See more information in chapter 3.3 Calibration.

2.6 Case and Cables

A conventional Tupperware was initially used as chassis for the PCB and the corresponding cable connections. This is low cost, easy to obtain and waterproof. The material is suitable for the easy installation of connectors. For the plug connections of power, sensor frame and scale, holes were drilled into the case and the connections or cable ducts were sealed if necessary. D-Sub 9-pin connectors (Figure 12) are suggested for the sensor frame (with microphone and temperature sensor). As a solid alternative AC 200V 5A connectors with 16mm and 8 wires are recommended (Figure 13). A 12V DC power plug (Figure 14) is recommended as a connection for photovoltaic power.

Figure 12: D-Sub 9-Pin Plug for Sensorframe connection

Figure 13: AC 200V 8-Pin Plug

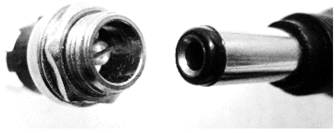


Figure 14: DC power plug

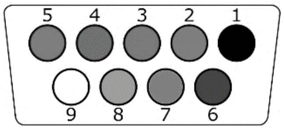


Figure 15: 9-Pin D-Sub pinout (backside)

To connect the sensor frame cables with 9-Pin D-Sub correctly, you can use figure 15 and the coloured cable code (1 – red, 2 – yellow, 3 – blue, 4 – white, 5 – black, 6 – orange, 7 – violett, 8 – brown, 9 – green). Figure 16 shows the open case with screwed PCB with step-down converter, A/D converter and Raspberry Pi as well as screw terminal block (blue) for easy cable wiring without solder connection. The plug connections for sensor frame (D-Sub 9 plug) and photovoltaic power (DC power plug) are connected to the screw block. There are also cable ducts for the humidity sensor (DHT22) and the scale (H30A load cell).

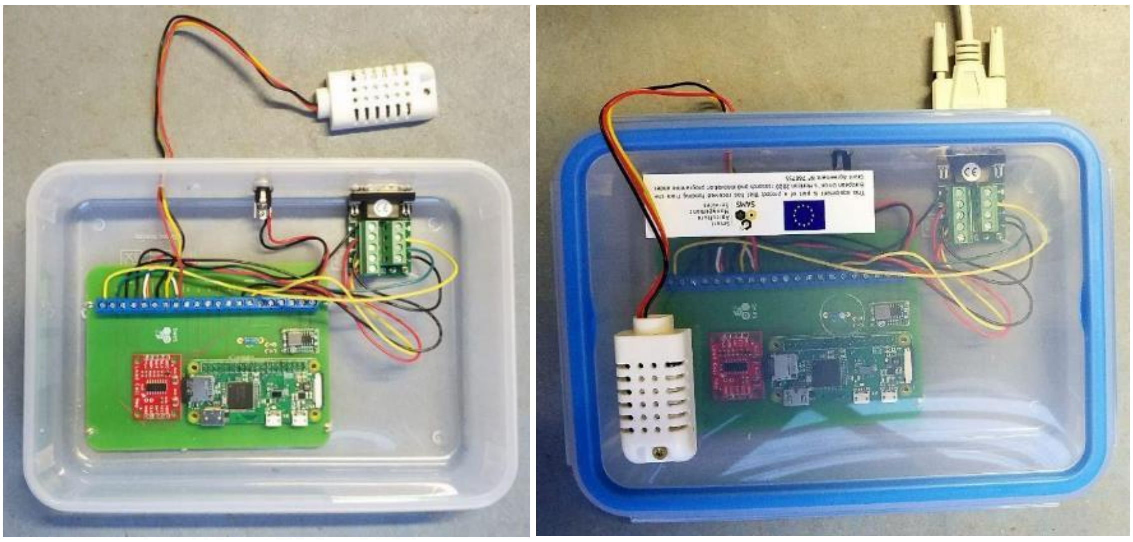


Figure 16: SAMS HIVE hi-fi Prototype with sensor for outside temperature and humidity and cable connector for power, sensor frame and scale

2.7 Sensor Placement

In order to find the best position for the sensors, various possibilities have been tested. Data quality, installation effort and disturbance of the bee colony were main factors. Two options have been found to be relevant in practice. The first option was the installation of the PCB in a brood frame of the bee colony (Figure 17). The brood frame was hung as the outermost frame on the edge of the beehive (Figure 18). Both the temperature sensor and the microphone were in the same place in the brood frame. To avoid contamination of the PCB, both sides of the brood frame were covered with wire mesh. In spite of covering, there was contamination by wax plates. Propolis and honeycomb construction posed no problems. This is probably due to the chosen distance to the closest honeycomb, the so-called Beespace. The advantage of this variant is the simple connection to the sensors without special cable routing. In addition, no separate case is necessary. With the acoustic data this placement resulted on the one hand in occasional clipping by direct contact with bees, on the other hand the distance to the central part of the brood nest was large. This is due to the fact that the nest is usually located in the middle of the beehive, but the sensor frame is at the edge. This distance has a negative effect on the data quality of the acoustic data. For the temperature measurement the installation height as well as the distance to the centre of the brood nest is also decisive. With increasing distance to the brood nest it is difficult to differentiate from the outside temperature. Again, it makes sense to place the sensor closer to the nest.

The recommended installation option is to use a sensor frame above the brood chamber (Figure 19). The sensor frame contains microphone and temperature sensor (Figure 20). The sensors are installed centrally in the frame so that they are located above the brood nest. This allows the use of the natural heat flow. The installation is also easy here. The frame is placed horizontally on the brood chamber and the sensors are connected via cable to the PCB with the computer unit (Chapter 2.6). The main advantages are the clear separation of the colony and the higher data quality. With a beekeeping control the sensor frame can be easily removed from the colony. In addition, the computer is not in the brood chamber, so there is less Wi-Fi radiation in the colony. Figure 21 shows the installed sensor frame at the colony and the monitoring system.

Figure 17: Sensor placement in an empty brood frame (Witzenhausen, 22.03.2019)

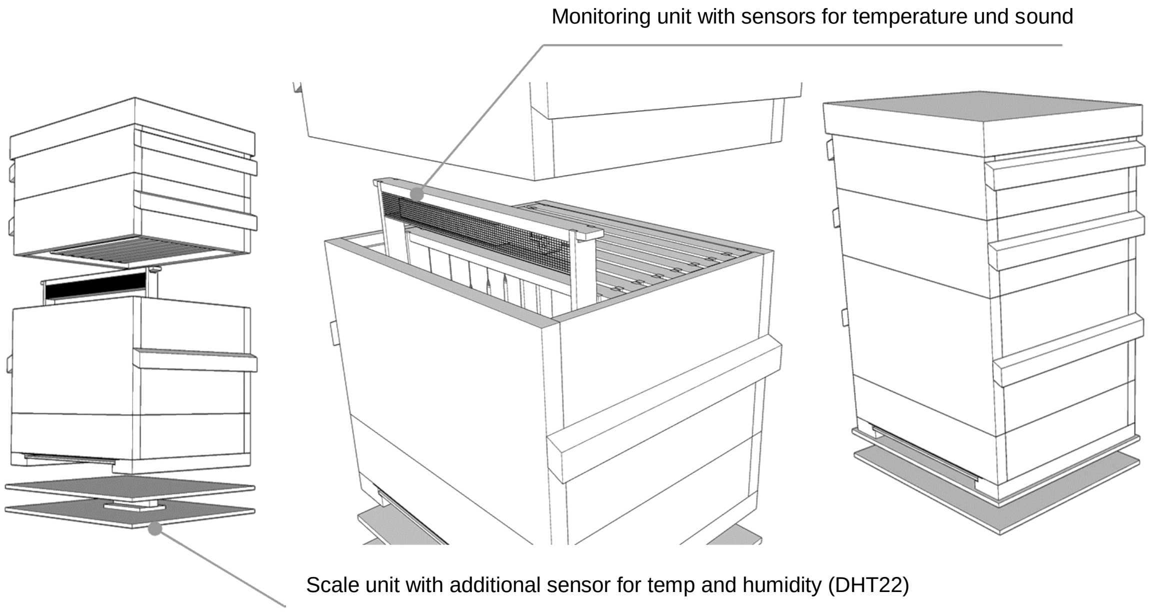


Figure 18: Sensor placement inside the brood chamber

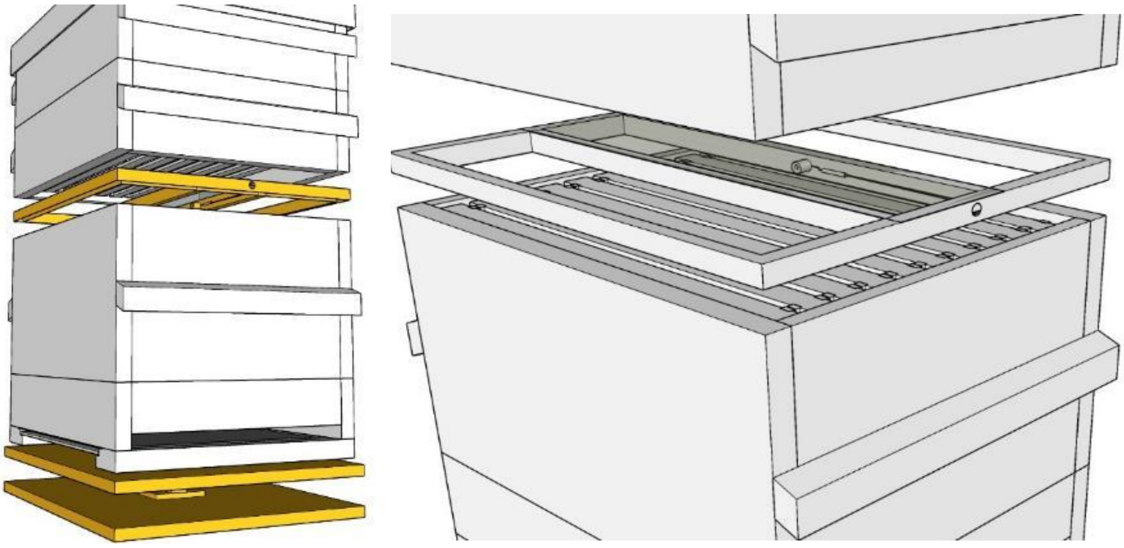


Figure 19: Sensor placement in extra sensor frame between honey and brood chamber

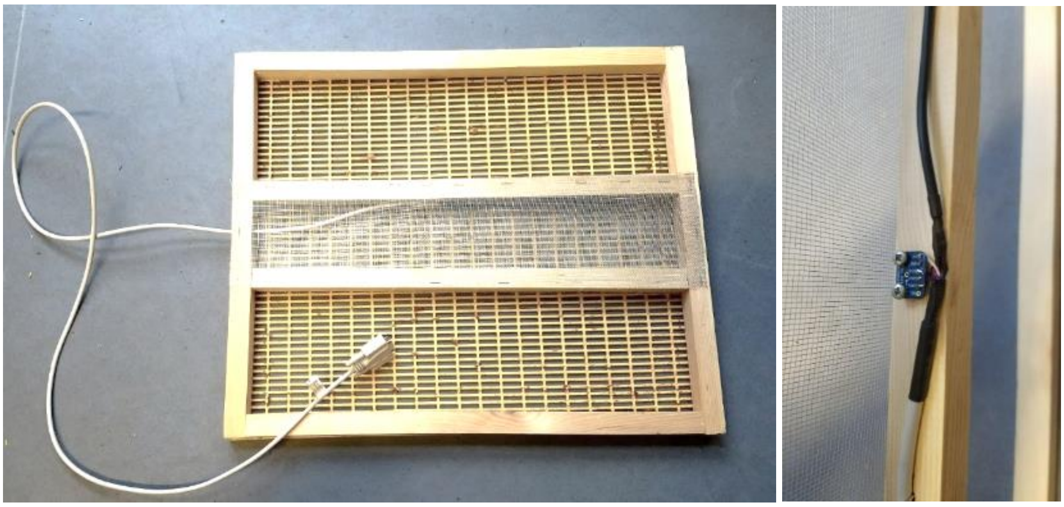


Figure 20: Sensor frame with temperature sensor (DS18B20) and Microphone (SPH0645)

Figure 21: Installed SAMS HIVE hi-fi Prototypes with Sensor frame and Scale
at Testsite Witzenhausen (13.05.2019)

3. Installation

The SAMS HIVE hi-fi prototype was installed at the test site Am Sande in Witzenhausen as well as at an installation workshop (chapter 3.6) in Ciwidey, Tanikota and Bandung on West Java in Indonesia and at the Bee Institute Holeta in Ethiopia. For the installation, the electronic components need to be soldered to the PCB as marked on the PCB (chapter 2.4). Subsequently, the board must be fixed into a case and the plug-in connections installed. Also the microphone and temperature sensor must be placed in the sensor frame (chapter 2.7) and connected to the PCB. The following chapters deal with the construction and calibration of the scale as well as a basic software configuration, a function check and setup of the data warehouse.

3.1 Scale installation

The scale unit consists of a load cell (BOSCHE H30A, chapter 2.3) and a metal plate on each side. The metal plates are each screwed onto the load cell with a spacer. The metal plates and the spacer are made of aluminium. Figure 22 shows the dimensions of the metal plate and the spacer with the appropriate hole dimensions. The outer dimensions and holes are not fixed and can be varied. According to the manufacturer a length and width of 40cm should not be exceeded. The thickness of the material is 10mm for the metal plate and 6mm for the spacers. The holes in the metal plates shown in Figure 22 are used to attach the load cell (7mm) and a wooden plate to the scale unit (with M10 thread). The wooden plates should be of sufficient thickness to be able to take the maximum weight of the beehive. Figure 23 shows the dimensions of the load cell and the attachment of the metal plates and spacers. The cables of the load cell are color-coded and must be assigned to the appropriate labelled screw terminals for connection to the PCB.

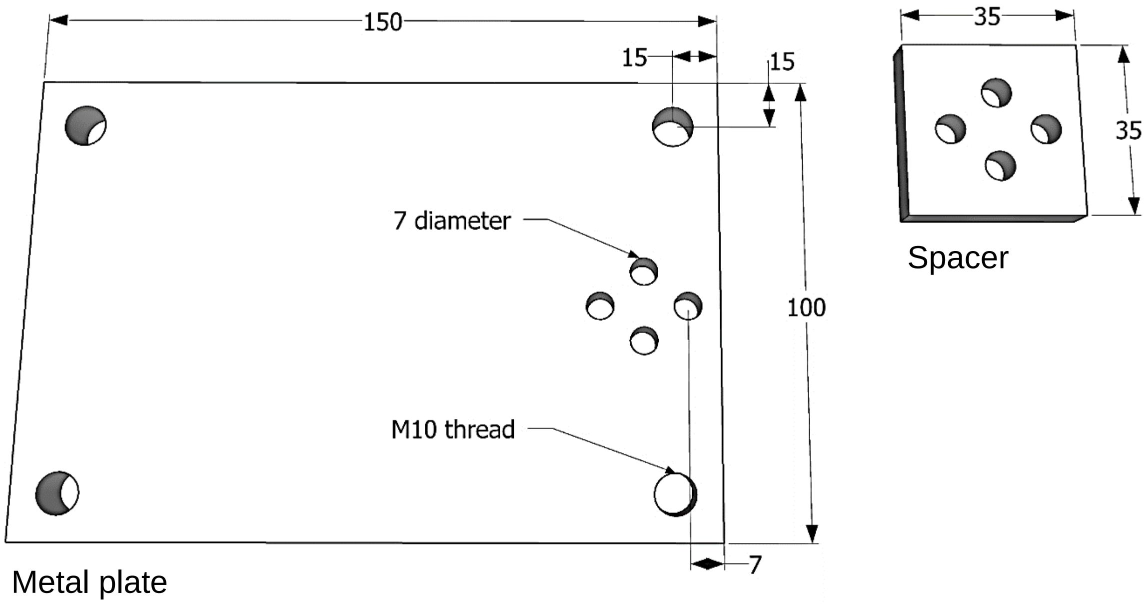


Figure 22: Measurements of metal plate and spacer for scale setup

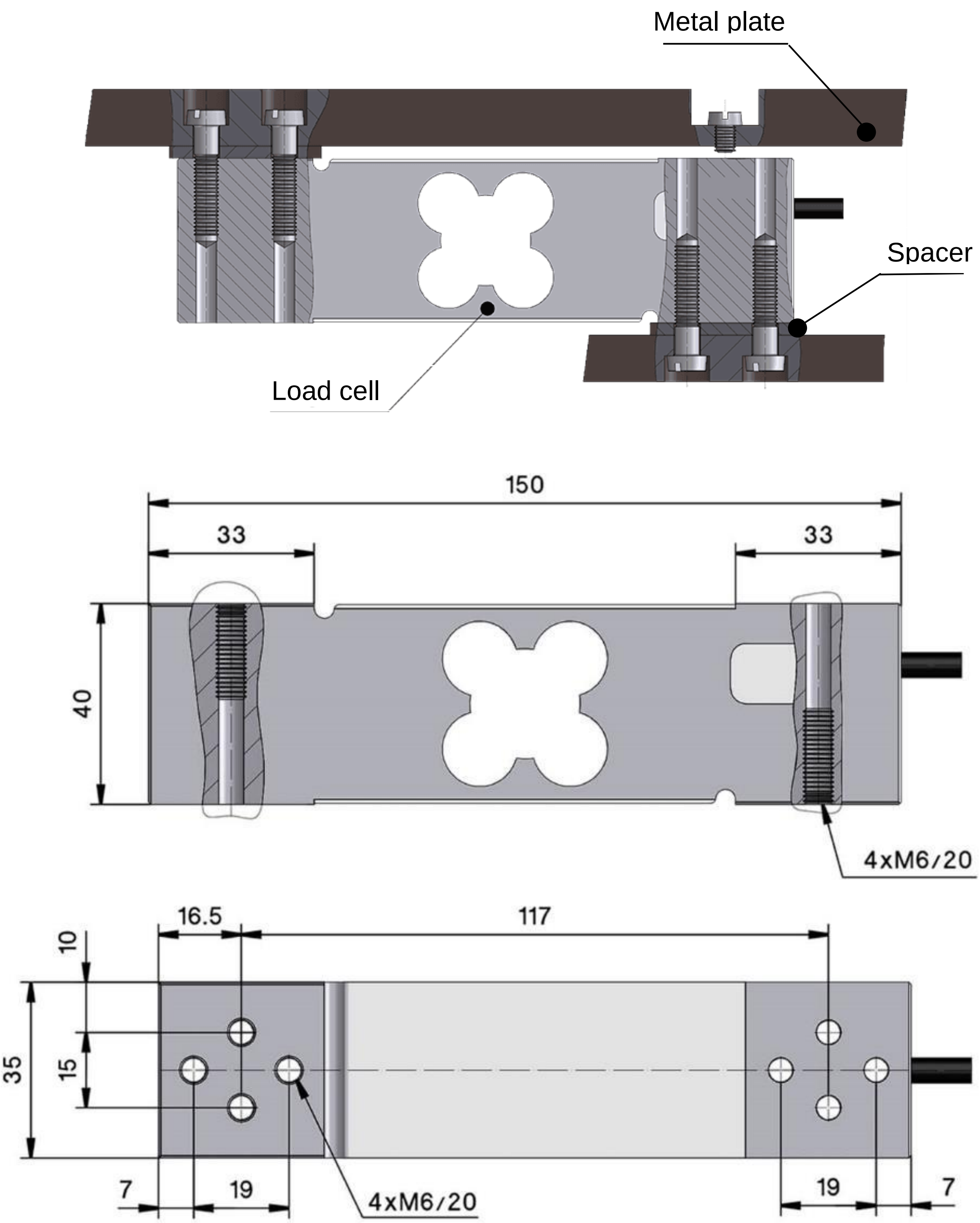


Figure 23: Measurements and Setup of Load cell (bosche.eu)

3.2 Configuration

Once the hardware has been successfully assembled, the software on the Raspberry Pi must be installed and configured. The configuration consists of importing the Auth0 credentials to give the system a unique recognition. Additionally Wi-Fi and the power management WittyPi can be enabled. The last step is to calibrate the system with the web application. The function test and data warehouse mapping can be done to assign location and name to the sensor data.

Image installation

To install the software, an image file (https://sams.science.itf.llu.lv/images/prod4-wittypi.zip) can be downloaded from the SAMS project website and placed on a standard micro-SD card. To install the image on the micro-SD card you can use the open source software w32 Diskimager (https://sourceforge.net/projects/win32diskimager/). The image file contains the Raspberry Pi OS Raspbian Stretch (https://www.raspberrypi.org/downloads/raspbian/) as well as the software for the SAMS Monitoring System (https://github.com/sams-project/), the WittyPi Mini (chapter WittyPi Setup) and the open source application BerryLan (chapter Wi-Fi Setup). The SAMS software can also be installed on an existing Raspbian version.

Credentials for Data Warehouse

The Auth0 service is used to recognize the individual SAMS monitoring systems and sensor data on the web server (data warehouse). Auth0 provides authentication and authorization as a service (https://auth0.com). This service generates a unique number (client_id) for each system which is used in the data warehouse to map the sensor data. During upload, sensor data is always transferred to the server together with the respective client_id. To assign a unique client_id to each system, a file with the name "Credentials.ini" must be created in the main directory, the so-called boot folder, of the SD card. The file should contain the following text, where the yellow marked lines need to be replaced by the appropriate client_id and client_secret. Client_id and client_secret will be generated on the website of the Data Warehouse (https://sams.science.itf.llu.lv).

```
[DEFAULT]

client_id = Zy9Jtu1uXEIw94OP3cLMeDhSK5OAYXWT

client_secret = Y5G1LTWaZh-P77A8xsp8YR-NWPdW6GKnd0

audience = sams-dwh-web-api

grant_type = client_credentials

data_url = https://sams.science.itf.llu.lv/api/data

token_url= https://sams-project.eu.auth0.com/oauth/token

ondo_key= 666
```

Wi-Fi Setup

Wi-Fi for the Raspberry Pi must be set up using a smartphone before the software can be configured. BerryLan is pre-installed on the SAMS image for this purpose. After the first start of Raspberry Pi with the SAMS image, a connection can be established via Bluetooth and the BerryLan app with Android (https://play.google.com/store/apps/details?id=io.guh.berrylan) or iOS (https://itunes.apple.com/us/app/berrylan/id1436156018). In the BerryLan app, the SSID of the mobile Wi-Fi router and the corresponding network key can be entered. BerryLan displays the IP address for the Raspberry Pi in the network. The IP address can be used to access the Raspberry Pi via an Internet browser and perform further calibration (chapter 3.3 Calibration). If the time zone, measurement interval (chapter WittyPi Setup) or root password should be changed, a connection to the Raspberry Pi must be established via an SSH. This can be done e.g. with Putty (https://www.putty.org/). The default access data are required for this (user: pi, password: samsrocks).

Country Specifications and Internalization Options

To change the time zone or the pre-set access data, a connection can be established via SSH (e.g. https://www.putty.org/). With the command `sudo raspi-config` settings can be made. For more information see the following manual:

https://www.raspberrypi.org/documentation/configuration/raspi-config.md.

WittyPi Setup

To make changes in the power management the on and off times of the WittyPi Mini can be set via a schedule script. This can also be done via the console via SSH connection. To generate a new schedule script (Figure 24), use the following link: http://www.uugear.com/app/wittypi-scriptgen/. For general information on configuring the Witty Pi Mini, see:

http://www.uugear.com/doc/WittyPiMini_UserManual.pdf

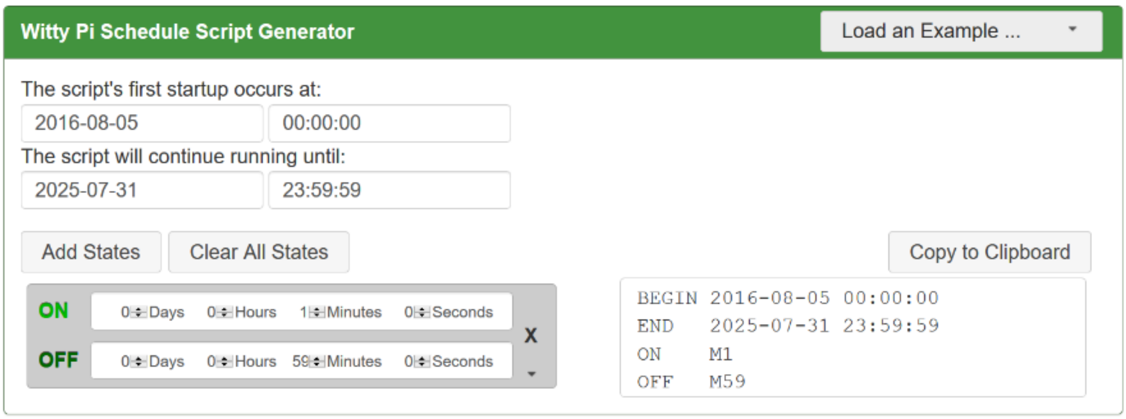


Figure 24: Witty Pi Schedule Script Generator (uugear.com)

3.3 Calibration

To calibrate the scale, it requires the IP address of the particular monitoring system (chapter Wi-Fi Setup). To establish a connection to the calibration page, the IP address of the Raspberry Pi is entered into an Internet browser. For calibration, any weight must be removed from the balance. After starting the calibration, an object with a known weight (e.g. 10kg) should be placed on the scale. The system can then be calibrated and restarted. After the first restart, the measurement begins. If a defined 10kg weight is available and several systems have to be calibrated, there is a quick calibration available which already has a pre-set weight of 10kg. Figure 25 shows the web application guiding through the calibration steps.

Figure 25: SAMS Scale calibration software

3.4 Logging

To check the measurement data after the initial start, the IP address with the ending /api (e.g. 192.168.8.1/api) can be entered in the URL bar of a browser. This fetches the data from the internal web server and displays it in a table. Furthermore, the current activity of the monitoring system can be checked in a prototype web application. The client_id must be entered in the Web App. After successful access to the logging data, it is listed in the browser window. The status messages are highlighted in color to indicate potential errors. Figure 26 shows the web app during a measurement. The SAMS weblog displays a status message with the respective date and time if, for instance, sensors are not connected or errors occur during upload. The prototype of the SAMS weblog is temporarily hosted at the following URL: http://clients.bee-activity.rocks/

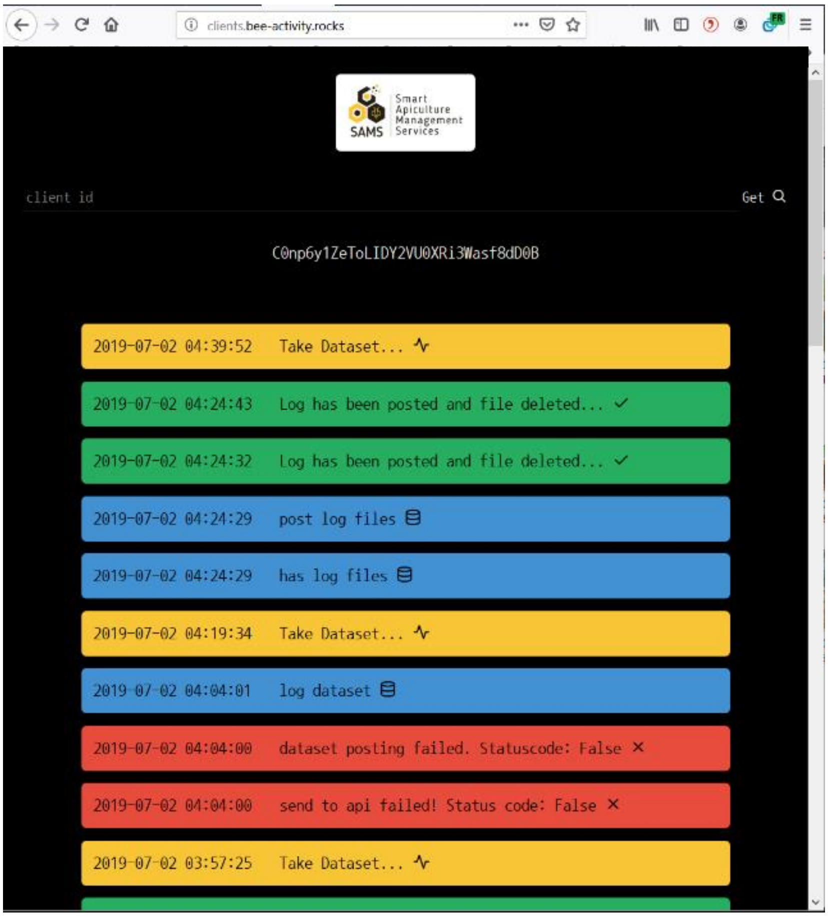


Figure 26: Screenshot of SAMS weblog for debugging

3.5 Data Warehouse Sensor Mapping

A Data Warehouse (https://sams.science.itf.llu.lv/) was developed by our project partners at the Latvia University of Life Sciences and Technologies in Jelgava to store and process the collected data. A Data warehouse (DW) is able to operate with different data inputs and handles the data processing. Figure 27 shows a screenshot of the DW start page. After registration and login in the DW, client structures can be set up, so-called user nodes (Figure 28). User nodes can contain e.g. groups, devices or elements. The individual nodes can be given additional properties, such as location data or specific sensor mapping. For the sensor mapping a client_id (chapter Credentials for Data Warehouse) and different sensor types are assigned to the node. Figure 29 shows an overview of the installed SAMS monitoring devices at the test site Am Sande in Witzenhausen, Germany. The last data upload can be displayed in the device details section (Figure 30). More information about the UNILV Data Warehouse can be found at: https://sams-project.eu/scientific-papers-and-abstracts/ or soon at our project website.

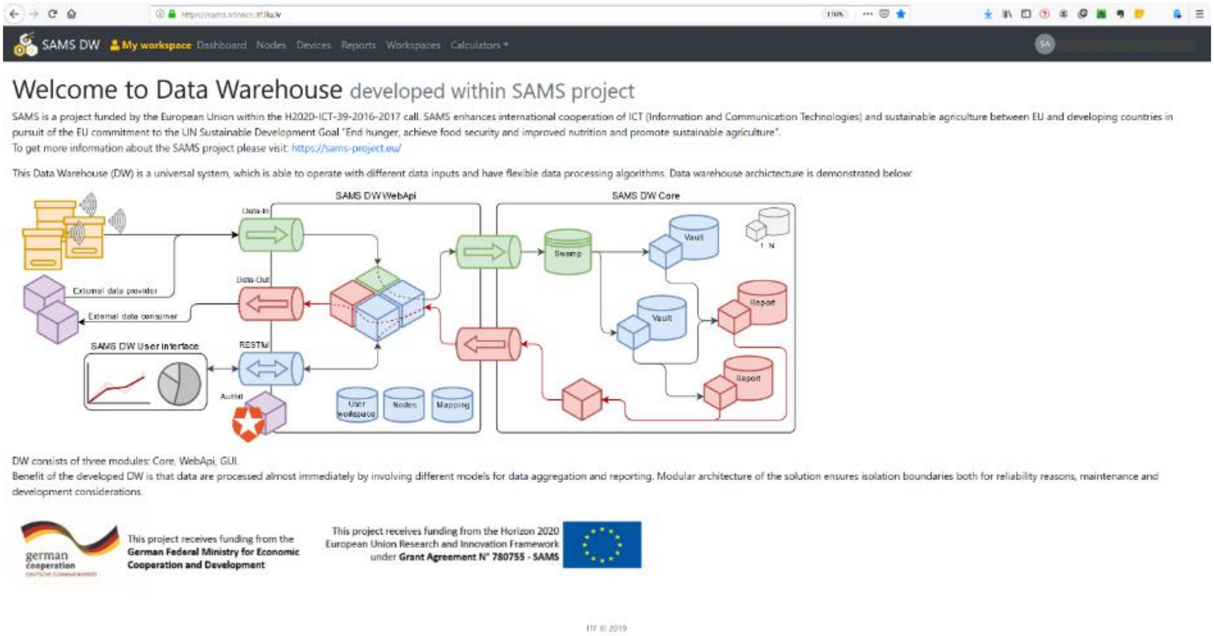


Figure 27: SAMS Data Warehouse (https://sams.science.itf.llu.lv/)

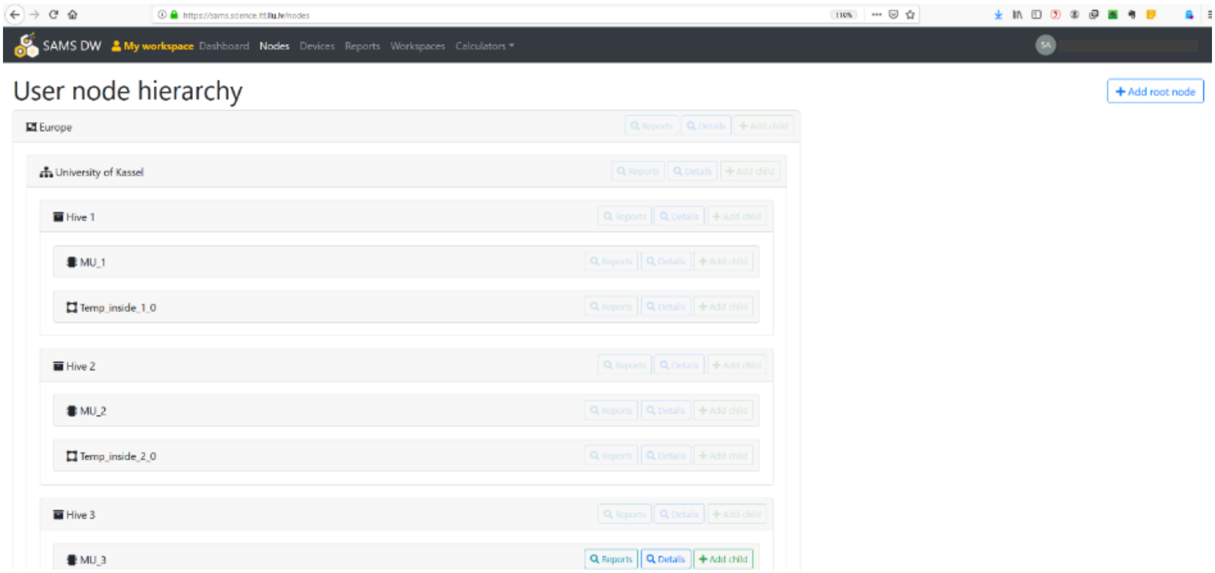


Figure 28: SAMS DW User node hierarchy for client mapping

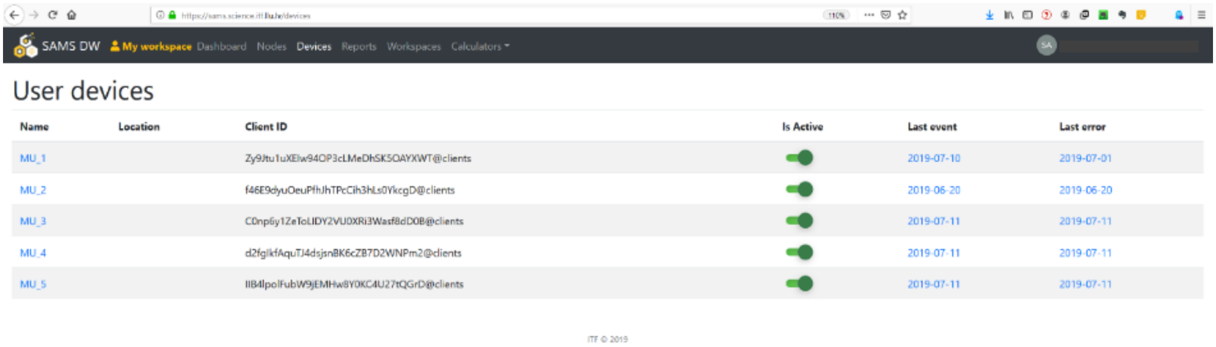


Figure 29: SAMS DW User devices

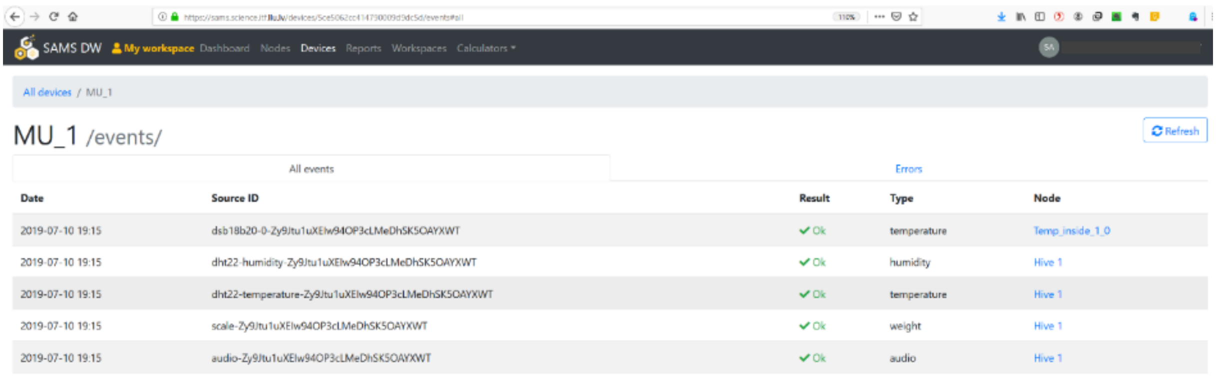


Figure 30: SAMS DW Event and Error protocol

3.6 Installation Workshop ET / IDN/ WIZ

Five SAMS HIVE hi-fi monitoring systems were installed in bee colonies in the project partner countries Indonesia and Ethiopia to earn further knowledge for the development of SAMS software and a Decision Support System (DSS) for beekeepers. In West Java, Indonesia, monitoring systems were installed in Tanikota, Ciwidey and Bandung. In Ethiopia the monitoring systems were installed at the Bee Research Center in Holeta, close to Addis Ababa. The bee colonies are supervised by experienced beekeepers and recorded on the health status, peculiarities and practice-relevant information on the condition of the bee colony. Within the scope of an installation workshop in March and April 2019, the monitoring systems were built in the partner countries together with the development team of the University of Kassel and installed in bee colonies. The project partners were informed in detail about the development in an introduction seminar and in a practical part they built together and exchanged difficulties, problem-solving strategies and know-how. A film team was available to record the key steps for internal use. A short clip about the project was produced during the workshop in Ethiopia (https://www.youtube.com/watch?v=qQbTixlhUmo). A second installation workshop was held in the partner countries in July 2019 and 10 further SAMS monitoring systems were built and partly already installed. The workshops provided important insights for further development (chapter 5). The photos in Figure 31 - 37 show the construction and installation of the monitoring systems.

Figure 31: Monitoring System and Photovolataic Components ready to install

Figure 32: Beehive before and after installation of the Monitoring System in Ciwidey, Indonesia

Figure 33: Beehives with Monitoring Systems ready to install

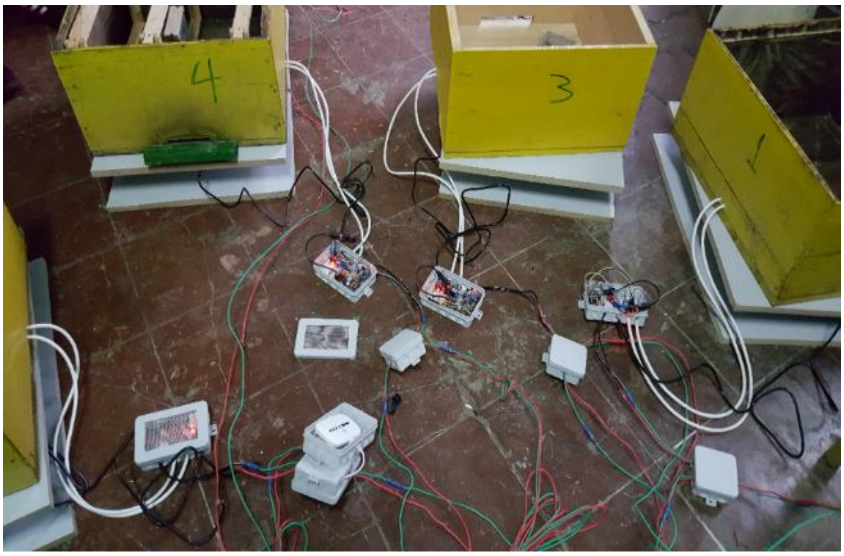


Figure 34: Beehives for Monitoring System at Holeta

Figure 35: Installed scale unit with Monitoring System in Tanikota, Indonesia

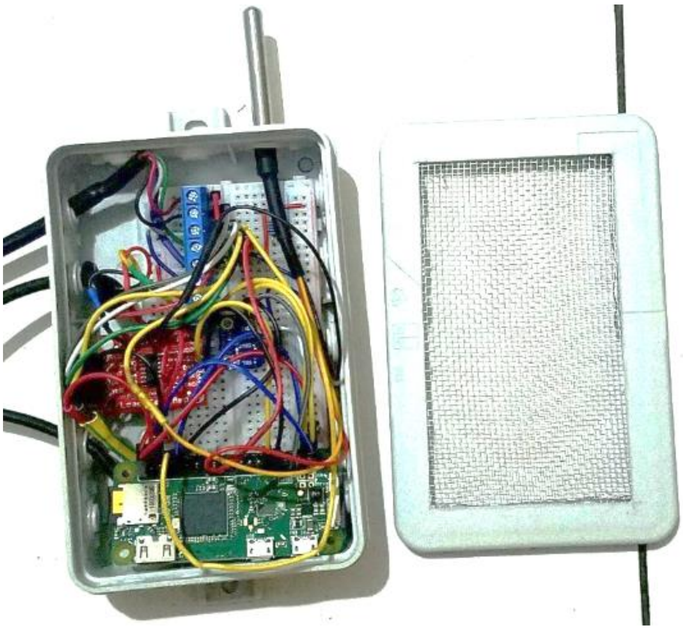


Figure 36: SAMS HIVE hi-fi Prototype on Breadboard

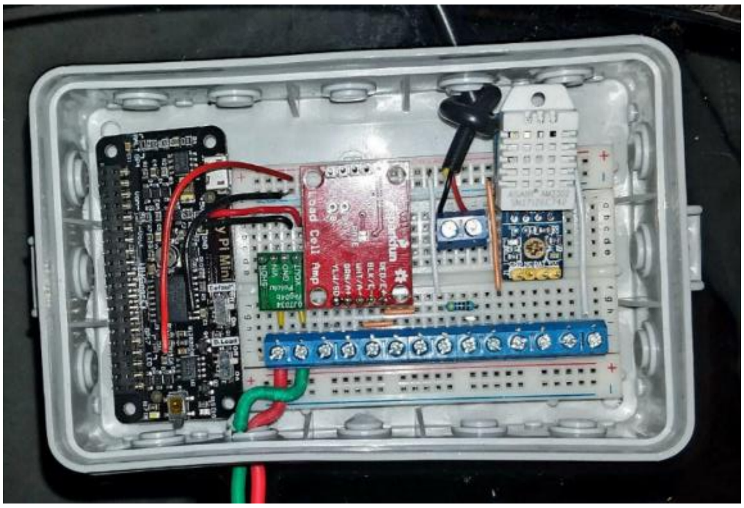


Figure 37: SAMS HIVE hi-fi Prototype on Breadboard in detail

4. Measurements and data processing

Seven SAMS HIVE hi-fi prototypes are currently implemented at the location "Am Sande", Witzenhausen, Germany. Each system records audio and estimates the power spectral density. This is done on an average rate of 6 cycles per hour. Each microphone is located inside a beehive, which are positioned next to one another. As a preliminary data exploration on spectral data for day vs. night time the dataset discussed here has been obtained in the first week of June, 2019.

Frequency Range and Dynamics

Suitable for current investigations, a frequency region from 40 Hz up to 4 kHz is shown in figure 38. The system records data with a sampling rate of 16 kHz, thus, a frequency analysis up to 8 kHz may be exploited. Figures show 6-h-averages, recorded at day and night time, respectively from 10Am to 4PM and 10PM to 4AM.

The microphones used for the SAMS system are manufacturer-related not calibrated. Therefore, no conclusions about the absolute sound pressure level (in dB SPL) nor the difference between individual hives may be drawn.

Common to all hives however is less power during night versus day time. This individual difference is plotted in figure 39, showing the all-hive average in black, shaded areas indicates standard deviation. The average difference of acoustic power across the frequency spectrum between day and night is 7.3 dB (Sigma: 1.9 dB), whereas more sound power is measured during daytime. Counterintuitively, the difference in sound power does not necessarily imply a less activity of the bees.

Sounds that can be contributed to bees are mainly located in the frequency band of 100 Hz to 300 Hz, depending on the current active and stress level of the bees. Figure 39 shows power peaks at a fundamental frequency of 125 Hz and another peak at a first harmonic at 250 Hz for each hive.

Comparing the acoustic power for these frequencies for recordings that were obtained during day and night time, no obvious difference is visible. Thus, the computed difference of 7.3 dB in level seems to be owned by environmental noise.

From the results so far, it is not possible to distinguish between "house-keeping" (night) and "gathering" (day) activity by means of visual exploration. A deeper investigation using computational evaluation and exploitation of several statistical models will follow.

Previous data recorded in autumn 2018 did show a difference in bee activity when comparing day and night time. The current dataset has been obtained in the first week of June. Thus, ongoing data collection will reveal seasonal effects.

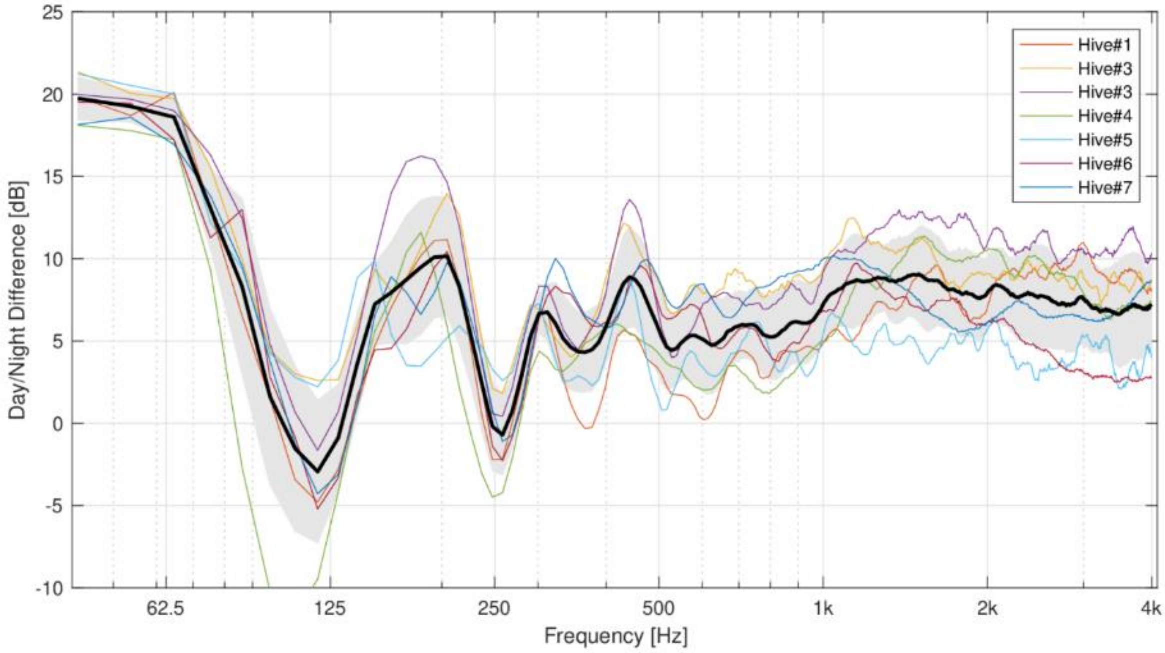


Figure 38: Acoustic power difference day/ night for all 7 beehives at testsite Am Sande in Witzenhausen

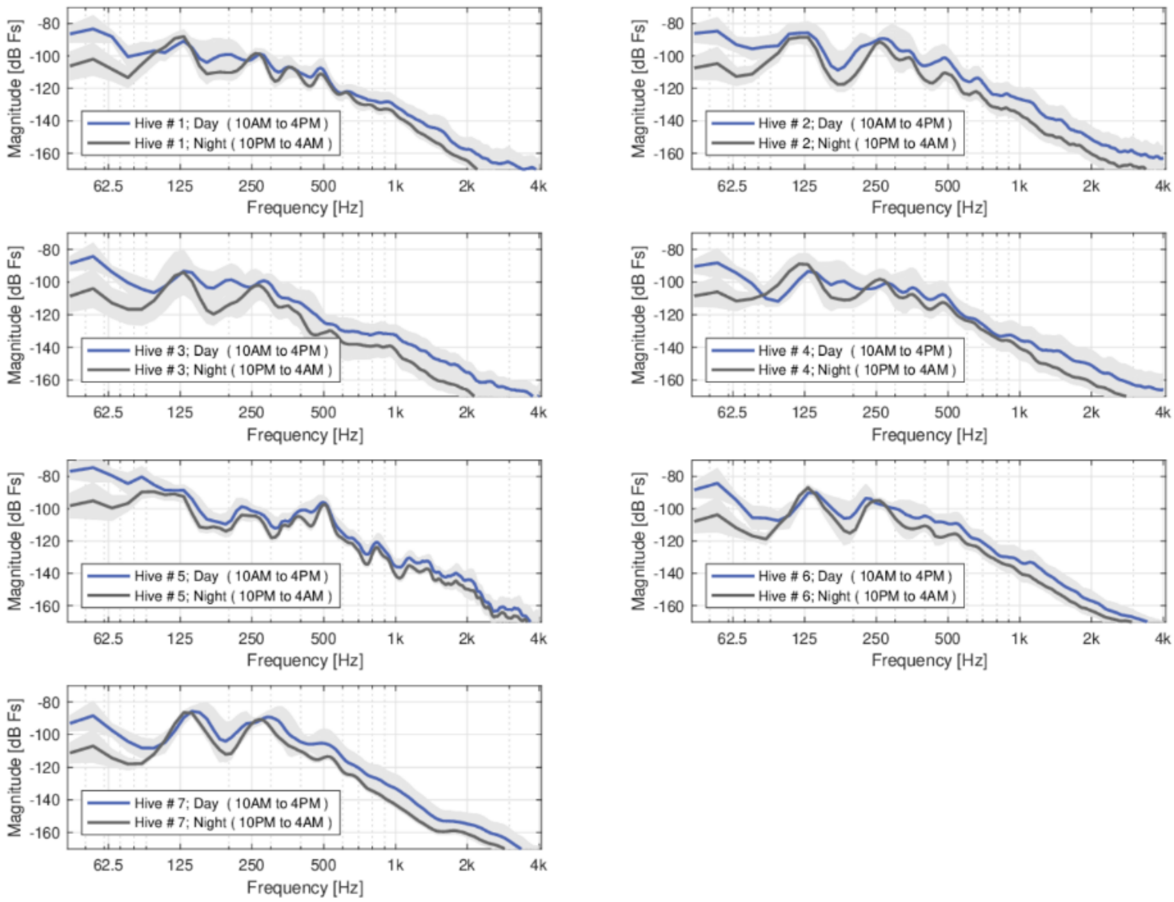


Figure 39: Specific acoustic power difference day/ night at testsite Am Sande in Witzenhausen

5. Further Development

In the further development the following changes shall be made:

- DHT22 sensor should be replaced by DS18B20, because of its robustness and because humidity measurement outside the beehive is not meaningful, as humidity values are often too high.
- The PCB will get more connections for DS18B20 sensors in order to be able to carry out detailed temperature measurements with several sensors if required (especially for bees breeding).
- The PCB design shall be redesigned to be able to reach the SD card outside a case.
- A 3d printable case will be designed.
- Female header plug will be used to install the raspberry Pi on the PCB.
- More project information shall be printed on the PCB.
- A sensor for monitoring the photovoltaic system could be implemented.
- The data transfer rate like upload speed could be read from the DW.
- An online interface to make changes to the Raspberry Pi config (measurement intervals, schedule script, acoustic measurement parameters, time zone).
- The calibration interface shall be adapted (Restart button, Config file option, Wi-Fi options, Credentials).
- A restart button could be provided on the PCB.
- Indicator lights could be installed to indicate specific faults or statuses.

Annexes

Links to Datasheets of the components:

Raspberry Pi Zero w:
https://cdn.sparkfun.com/assets/learn_tutorials/6/7/6/PiZero_1.pdf

WittyPi Mini:
http://www.uugear.com/doc/WittyPiMini_UserManual.pdf

SPH0645:
https://cdn-shop.adafruit.com/product-files/3421/i2S+Datasheet.PDF

DS18B20:
https://cdn.sparkfun.com/datasheets/Sensors/Temp/DS18B20.pdf

DHT22:
https://www.sparkfun.com/datasheets/Sensors/Temperature/DHT22.pdf

H30A:
https://www.bosche.eu/media/pdf/65/40/2c/Plattform_Waegezelle_H30A58906ecd3373f.pdf

HX711:
https://cdn.sparkfun.com/datasheets/Sensors/ForceFlex/hx711_english.pdf

E5330:
https://images-eu.ssl-images-amazon.com/images/I/91I1uf1EkGS.pdf

Mini-360:
https://cdn.solarbotics.com/products/datasheets/mp2307.pdf

Sun Plus 50:
https://produktinfo.conrad.com/datenblaetter/1400000-1499999/001485909-da-01-ml-MODUL_SOLARKIT_SOLAR_RISE_ONE2_50W_de_en.pdf

Eco 10:
https://www.phocos.com/wp-content/uploads/2018/06/ECO10_datasheet_final_06112018_english.pdf

Project website: www.sams-project.eu

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