International Partnership on Innovation

SAMS - Smart Apiculture Management Services

Deliverable N°6.4

Transfer Study on Technology and Services

Work package 6

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SAMS consortium partners

Logo	Partner name	Short	Country
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH (Coordinator)	GIZ	Germany
UNIKASSEL VERSITÄT	University of Kassel	UNIKAS	Germany
KARL-FRANZENS-UNIVERSITÄT GRAZ UNIVERSITY OF GRAZ UNI GRAZ	University of Graz (Institute for Biology)	UNIGRA	Austria
Latvia University of Life Sciences and Technologies	Latvia University of Life Sciences and Technologies	UNILV	Latvia
iceaddis	ICEADDIS – IT-Consultancy PLC	ICEADDIS	Ethiopia
IQQO Oromia Agricultural Research Institute	Oromia Agricultural Research Institute, Holeta Bee Research Center	HOLETA	Ethiopia
Universitas Padjadjaran	University Padjadjaran	UNPAD	Indonesia
PRIMARY TRAINING & CONSULTING	Commanditaire Vennootschap (CV.) Primary Indonesia	CV.PI	Indonesia

List of Abbreviations

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 behavioral response
- Implementation SAMS Business cooperation

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Executive summary

The study addresses the transferability of the field of application for the SAMS HIVE system to support individual beekeepers in the context of queen breeding selection as an example and thus presents a method for the further development and application of the SAMS technology. A comprehensive list of other existing monitoring devices and projects was compiled and contextualised. It is shown that the advantages of the SAMS HIVE system lie in its high degree of individualisation. A further highlight is the sensor combination including acoustics and adaptable data processing with model generation and visualisation via the so-called data warehouse. Further sensors for use with the HIVE system are also listed and evaluated in the context of bee health. It was found that the existing sensor combination already covers a wide range of possibilities and that sensor extensions would only be necessary in very specific cases. Standards and guidelines for the HIVE system are also discussed. BeeXML as a standard for data exchange was identified as a suitable option.

1. Concept of a follow-up study on bee-management and -health

The aim of the transfer study is the optimization of breeding selection with the help of sensors (HIVE system) in honey bees to improve bee health and productivity. The varroa mite introduced from Asia is currently one of the biggest problems in beekeeping. Untreated, this parasitosis usually leads to the death of bee colonies. The control is mainly done with chemical means, in organic beekeeping with less selective organic acids and essential oils, which on the one hand burdens the vitality of the colonies and on the other hand the whole beekeeping industry through recurring costs of means and labour.

The starting point "prevention by breeding for selection characteristics", such as varroa-sensitive hygiene behaviour (VSH) and low varroa reproduction (SMR), has decisive economic significance here and thus leverage effect for the sustainable relief of the entire beekeeping sector. However, the successful breeding work and the breeding value estimation of honey bees requires solid expert knowledge and time-consuming efforts of the breeder. Also, regular intensive controls to assess the condition of the respective breeding colony by the breeder are necessary, but detrimental to the health of the colony.

The use of sensor technology to support breeding selection offers considerable potential here compared to conventional breeding management to accelerate and improve breeding progress. The aim of a follow-up project is to optimize breeding work by identifying objective indicators through AI-supported data exploration. For this purpose, breeding populations are continuously monitored by sensors and correlated with the breeding traits recorded by the breeder. In addition to general parameters such as population strength and development, VSH, SMR, swarm tendency and winter breeding tendency are investigated to enable improved breeding progress.

1.1 Aims

- Monitoring of the breeding colonies by a bee monitoring system (HIVE) developed by the University of Kassel and tested by the SAMS project and the simultaneous conventional recording of breeding characteristics by a bee breeder
- Identification of indicators and development of prognosis models from the above-mentioned data for early detection of latent swarming tendencies, winter brood and varroa tolerance by data exploration
- Reduction of invasive interventions (visual control) in the bee colony to minimize negative influence on the breeding colonies
- Real-time detection of desired selection features, thus faster reactions to undesired selection features and thus minimization of losses
- Objectification of the evaluation of breeding traits through soft sensors
- Identification of previously unknown interactions between selection characteristics using multivariate procedures

2. Current issues of beekeeping management / activities

The vitality and productivity of bee colonies are a prerequisite for high pollination performance of cultivated and wild plants. The economic benefit of pollination exceeds the value of honey production by a factor of 10 to 15 and amounts to approximately 2 billion euros annually in Germany and 70 to 100 billion euros worldwide (Barrios et al., 2017). The vitality of honey bees is influenced not only by genetic predisposition, but also by biotic (parasites, viruses) and abiotic parameters (pesticides, climatic effects). Recent studies show that high losses of bee colonies are particularly due to the combination of the use of neonicotinoids and infestation with the varroa mite (Straub et al., 2019).

In the context of this worldwide problem, breeding improvement with a focus on vitality parameters is therefore becoming increasingly important. Breeding improvement is not only desirable in terms of vitality and productivity, but also has an important leverage effect in coping with future climate-related effects such as area shifts of insect populations, changes in biotope composition, weather conditions, increased parasite infestation due to warmer winters (Conte et al., 2008).

Conventional monitoring of parameters for breeding improvement is very time-consuming and includes regular manual inspection, which is a disturbing intervention in the colony. Even the opening of the lid acts as a stressor on the bee colony, and (too) frequent checks can disturb the natural processes in the colony so lastingly that it can no longer resist negative environmental influences sufficiently and is no longer able to respond. (Büchler et al., 2010). A non-invasive, sensory and therefore objective monitoring of vitality parameters shows here a special potential to support the breeder. On the one hand, the disturbance of the breeding population can be kept as low as possible by reducing visual inspections. On the other hand, the monitoring by sensors allows an analysis by multifactorial and multivariate data exploration, which can be used as a basis for prediction models. One example is the early detection of swarm behavior by means of audio, temperature and humidity sensors. (Ferrari et al. 2008). However, the applicant is not aware of any work of sensor-assisted breeding.

Studies show that especially acoustic data can be used to detect the state of the bee colony. For example, the analysis of acoustic data from bee colonies with a multiclass classification could provide the basis for the detection of queenlessness (Robles-Guerreroa et al., 2019). Furthermore, Nolasco et al. (2019) demonstrated the potential of neural network-based machine learning methods for the detection of queenlessness. Data loggers were used to measure temperature and humidity changes in different parts of the hive (Human et al., 2006). Rangel and Seeley (2008) used image and audio data to detect the movement and sounds of bees in the hive. Infrared radiation was used to study the temperature of the hive during the winter break and to differentiate the temperature of individual bees (Eskov and Toboev, 2011). Bencsik et al (2015) found a strong correlation between measured vibration amplitude and the phase of the brood cycle in the hives using acceleration sensors. Also, Stalidzans and Berzonis (2013) can show correlations between temperature and different stages of the brood cycle.

2.1 Market-available ICT technologies for bee related remote monitoring

Similar projects for scientific and educational projects as well as open source and commercial available systems on the market are listed in Table 1. In summary, available projects and systems are diverse and have different goals. The classification and advantages of the SAMS HIVE system can be characterized as follows:

- A Sensor combination that has rarely been used in similar projects so far, but which is very well suited for issues of practical relevance as well as for science and research. The limitations of temperature and weight data acquisition as a sole parameter can be well complemented by acoustic data, which can reveal further correlations if necessary.
- Due to its modularity, the system can easily be expanded for other purposes and all components can be reused. Thus, the system can be well used and extended as educational material in schools or courses
- The system could also be marketed as a DIY kit, as no micro-components were used, requiring special tools
- All functions can be set in detail, even remotely via an online configuration interface, making it very useful also for scientific applications
- The possibility of online updates during operation and a detailed real-time error log in the online interface make the system attractive for open source further development and enables developers to react quickly to upcoming issues
- To save energy, a well-proven energy management system was chosen. All measuring intervals can be planned in detail and can be individually adjusted over days and weeks
- An offline mode enables even more energy to be saved and all data to be stored securely on the external memory, even during short-term Internet failures.

In the following table 1 known similar projects are listed:

Table 1: Similar projects (Source: https://colonymonitoring.com/)

Category	Description	Link
Scientific and educational projects		
Umweltspäher	Prof. Dr. Randolf Menzel and Uwe Greggers are researching about the neurobiology and the behavior of the honeybee and the environmental impact of neonicotinoids on bee colony behavior at the Free University of Berlin. Around since 2000.	http://www.honeybee.neurobiologie.fu-berlin.de/
HoneyBeeNet	The HoneyBeeNet project of NASA inspired many of us with the idea of creating a national data collection network for gaining insights into environmental conditions, nectar flow and bee forage information. Around since 2006. Based/originated in Maryland and Delaware, U.S. Wayne	https://honeybeenet.gsfc.nasa.gov/About/SHprotocol.htm
HOBOS - HOneyBee Online Studies	The HOBOS (HOneyBee Online Studies) project is an interactive educational project initiated and developed since 2006 by Prof. Dr. Jürgen Tautz from the University of Würzburg, based in Franconia, northern Bavaria, Germany. After their 10 years of history, they have a large presence, online and in the real world.	http://www.hobos.de/
Swarmonitor	Swarmonitor is a research project aiming to develop a tool for remote diagnostic monitoring of honey bee hives. The Swarmonitor project aims to develop a tool for diagnostic monitoring of honey bee colonies, by monitoring vibrations in the hive. The Swarmonitor Consortium is made up of beekeeping experts, scientists and experienced manufacturers of hive monitoring equipment from across Europe. Around since 2015.	http://www.swarmonitor.com/ https://www.youtube.com/channel/UCTiQ-om5teuUzGhszCiC-Qg
Build the Buzz	Build the Buzz is a national Citizen Science project which aims to help understand and	http://buildthebuzz.co.uk/

	address Honey bee decline. Build the Buzz is a national scientific project using hive monitoring equipment to provide a greater understanding of life within the hive. Through the use of sensitive technology we will be able to monitor honey bee activity 24/7, 365 days a year to have a better understanding life within the hive. Build the Buzz is a fundraising campaign launched by the British Beekeepers Association (BBKA) to undertake a national hive monitoring project. All equipment is supplied to the British Beekeepers Association at cost, by Arnia Ltd. Around since 2016.	
Open source / DIY projects		
The Bee Laboratory	The Bee Laboratory project monitors the behaviour of honeybees in urban surroundings. Beekeepers, scientists and artists examine the bee colonies in our rooftop gardens, our open air laboratories. We study the distributed intelligence of the honeybees: their behaviour, ecology and sociobiology. We monitor the bees and beehives with all kinds of eco-technology and we study the colony as a community. We research the interaction between the different colonies as well as the colonies' behaviour and development in relation to the urban environment. Around since 2009.	http://annemariemaes.net/projects/the-transparent-beehive-laboratory/
Hivetool	A great community effort in the U.S, around since 2010. They have currently over 20 hives on-line in California, Georgia, Iowa, North Carolina and South Carolina. Their sensor hardware is based on a RaspberryPi. There's also an alternative software for use with the HiveTool suite of software: https://github.com/rcrum003/HiveControl	http://hivetool.org http://hivetool.net/
BeeMonitor	Honey Beehive Monitoring Project Around since 2010.	https://beemonitor.org/
Projekt "Bienenwaage"	A project from Markus Euskirchen, based in Berlin, Germany. Around since 2011. By using low-cost hive scales and documenting	http://www.euse.de/wp/blog/series/bienenwaage/

	his development efforts in detail, Markus really is one of the founding fathers of a lot of other DIY projects in this field. Clemens Gruber worked together with him in the early days. Details: The sensor hardware is based on an ATmegaXXX. The telemetry data transfer is based on the RedFly WiFi Shield. The data acquisition backend is based on PHP.	
Temperaturüberwachung im Bienenstock	Michael Mietz runs his own temperature monitoring system, in which temperature values are regularly recorded in the honeycomb in a 3D arrangement. Around since 2011.	http://www.beeventure.de/interviews/interview-mit-michael-mietz.html https://www.imkerforum.de/showthread.php?t=25886
Beeograph	A project from a team around Petar Denev, based in Munich, Bavaria, Germany. Around since 2012.	http://www.beeograph.com/
Swarmy	Swarmy helps you to measure sound levels inside your beehives aka a digital apidictor. By James Moore. Around since 2012.	
The Bee Observatory	OKNO Bee Monitoring Technology. Around since 2012.	http://urbanbeelab.okno.be/doku.php?id=bee_monitoring_technology
Hivelogger	Bee hive monitoring through advanced telemetry applications and systems by Stephen Engel, based in Sacramento, California, U.S. Around since 2013.	http://www.hivelogger.com/
Open Source Beehives	A crowdfunded project making beehive designs and starting with monitoring based on the Smart Citizen Kit, using an ATmega32u4. Spin-off from the Institute for Advanced Architecture of Catalonia, Fab Lab Barcelona and Open Tech Forever. Barcelona and U.S. based, around since 2013. The sensor hardware is based on the Particle Photon.	http://opensourcebeehives.net/ https://github.com/opensourcebeehives/ https://community.akerkits.com/c/In-this-section-you-can-find-anything-related-to-our-sensor-enhanced-beehives

BeeLab Citizen Science Project	The Bee Lab project aims to use the power of technology and Open Design to enhance the practice of beekeeping – making it easier for beekeepers to care for bees in today's unpredictable environmental landscape. Using the principles of Open Design, we are bringing together a community of passionate, multi-disciplinary people to create customisable monitoring Around since 2014. Seems abandoned or didn't even take off.	http://www.beelab.org/
Honeybee Hive Monitoring (Hackerbee.com)	The goal of this project is to build a system that records data from a beehive at roughly 5 minute intervals for later analysis. Data will include temperature, humidity and weight of a beehive as well as temperature, rainfall and other data from a weather station. By Ken Meyer. Around since 2014.	https://hackaday.io/project/1741-honeybee-hive-monitoring https://github.com/Deamiter/HiveLogger http://www.apitronics.com/
Arduino Beehive monitor	An Arduino, GSM shield, solar powered bee hive monitor that sends temperature and humidity data to the Xively platform By Marc Curtis. Around since 2014.	https://hackaday.io/project/2453-arduino-beehive-monitor https://github.com/exmonkey206/beehive_monitor
Stockwaage from Imkerverein Nettetal e. V.	A project from Alexander Wilms, based in North Rhine-Westphalia, Germany. Around since 2015. It's a kind of a fork of the Projekt "Bienenwaage" as Alexander was in contact with Markus Euskirchen, so both projects share similar hardware and software components. Details: The sensor hardware is based on an ATmegaXXX. The telemetry data transfer is based on the RedFly WiFi Shield. The data acquisition backend is based on check_mk.	https://www.imker-nettetal.de/category/stockwaage/
BeeLogger	Markus Hies built a sensor node based on a Raspberry-Pi SoC computer. Around since 2015.	http://blog.hies.de/?cat=18

Nathan Seidles Digital Beehive	Nathan Seidle of SparkFun Electronics published a well known article about how he wired his beehive with some sensors. Around since 2015.	http://makezine.com/projects/bees-sensors-monitor-hive-health/ https://github.com/sparkfun/OpenScale
The Hive Project	A RaspberryPi based project using the “Pi Noir” infrared-sensitive camera. Around since 2015.	http://hive.honeybeegardens.net/
Computer vision bee counter	Counts bees in and bees out of a beehive. A RaspberryPi/PiCamera based solution by Antoine Letouzey. Takes a video input of a top-down view of the beehive entrance and uses the Munkres algorithm for CV crunching. Around since 2015.	https://github.com/guyver2/beehive which shares some video recordings of 2015: https://www.raspberrypi.org/files/bees/ https://www.raspberrypi.org/forums/viewtopic.php?f=43&t=109316&p=822342
BienenBoxWaage	DIY project by M. Kögel. Around since 2015.	http://guckimker.tumblr.com/BienenBoxWaage https://github.com/mkoegel/BienenBoxWaage
Arduino Datenlogger mit Stockwaage für Imker	A project from Raimund und Thorsten Gurzan, based in Lower Rhine region in Germany. Around since 2015. They have great, detailed documentation for the whole system. Details: The sensor hardware is based on an ATmega328. The telemetry data transfer is flexible: Ethernet, WiFi or over radio links (433 MHz, 2.4 GHz). The data acquisition backend is PHP.	http://beelogger.de/
Hiverize	Hiverize is a network for cooperative beekeeping and saving the bees. Founded by Carolin Zschippig and her team, based in the Free and Hanseatic City of Bremen. Around since 2015.	http://hiverize.org/
apiLink	A Bee Counter for 120€? An affordable Monitoring System supported by the Spanish Department of Environment and Food. By Dr. David Atauri, Jose A. J, Vadillo	http://beekeepingsensors.com/

	and Dr. Esther Mz Pastor. Around since 2015.	
4Bees	4Bees is an open platform founded by Mag. Dieter Metzler for innovative beekeepers and developers to develop products that improve the quality of life of bees and beekeepers. Based in Alberschwende, Austria. Around since 2015.	http://www.4bees.at/
beam-it / Frank Hartmann	Frank is developing beehive monitoring tools and is using hardware from Clemens. Around since 2015.	http://www.beam-it.de/apiary/
Geek4Bee	A great autonomous beehive monitoring project by Tomas Ivansky of Zoongo Ltd. also using the Seeeduino Stalker as sensor node platform, while currently looking at the Sodaq Autonomo. Around since 2016.	http://www.geek4bee.com/ https://github.com/Zoongo/BeeMonitor/
Imker Stockwaage	A project from Achim Pfaff, based in Lower Franconia in Bavaria, Germany. Around since 2016. Details: The sensor hardware is based on an ATmega168. The telemetry data transfer is based on an Itead 3G GSM modem.	http://www.imker-stockwaage.de/
Moonahbees Hive Monitor	A group of apiaries distributed around the Port Phillip Bay region of Victoria. Around since 2016.	http://www.moonahbees.net.au/?page_id=48 https://weteachme.com/rooftophoney/1013463-makers-workshop-build-a-solar-powered-electronic-hive-scale
The BEEP platform	A collaborative project by Marten Schoonman and Pim van Gennip building an ergonomic data entry app for beekeeping (aka. Elektronische Stockkarte) and a monitoring system. Around since 2016.	https://beep.nl/
Other resources		http://martenschoonman.blogspot.de/2016/03/digital-beehive-monitoring.html https://www.facebook.com/bijenstalbreukelen/

Save the Bees	A firmware for sensor reading aimed at beehive monitoring. The project is sponsored by Cisco, relayr and CSIRO for understanding bee colony collapse using IOT. Around since 2016.	https://github.com/save-the-bees/
Commercial projects		
CAPAZ GSM 200 Bienenwaage	Professional hive scale system from CAPAZ GmbH, based in Western Baden-Württemberg, Germany. Around since 2004.	http://www.bienenwaage.de/
BeeWise	A hive scale product and monitoring solution from a french manufacturer. Around since 2007.	http://www.beewise.eu/
Penso Bienenstock Wägesysteme	Professional hive scale systems from Martin Steppuhn and his team of Emsystech Engineering, based in Baden-Württemberg, Germany. Around since 2009.	http://emsystech.de/
BeeWatch	Professional hive scale systems from Biene & Natur GmbH, based in Upper Franconia, northern Bavaria, Germany. Around since 2011.	http://beewatch.de/
Hive Tracks	Hive Tracks from Dr. James Wilkes of Blowing Rock Software LLC and his team builds innovative beekeeping software. Based in North Carolina, U.S. Around since 2011.	https://hivetracks.com/
HiveSensors	HiveSensors from Arizona, U.S. offers compact wireless environmental hive sensors for use in experimental bee research. Around since 2011.	http://www.hivesensors.com/
Arnia	Arnia builds state of the art remote hive monitoring systems. Based in Northumberland, England. Around since 2012.	http://www.arnia.co.uk/
Bee Smart Technologies	Bee Smart™ is a remote diagnostic and monitoring station for any bee hive. The device collects vital health and productivity information by collecting in-hive temperature and humidity, analyzing the sound in the hive and tracking the change in weight. Bee Smart™ also tracks movement and informs beekeepers if their hives are displaced. The system acts as a real-time medical record for any bee colony. Bee	http://beesmarttechnologies.com/

	Smart™ saves time, makes operations smoother, brings down costs and may help increase yield. Bee Smart Technologies Inc. was founded by Ivan Kanev and Sergey Petrov. Based in San Francisco, CA. Around since 2012.	
Hivemind	Hivemind is an industry-leading product for keeping track of your hives in remote locations. The company builds remote hive weight measurement solutions for beekeepers with satellite uplinks for transmitting telemetry data. Based in Christchurch, New Zealand as a spin-off of Brush Technology. Around since 2013.	http://hivemind.co.nz/
Bienenstockwaage from Wolf-Waagen	Professional hive scale system from Wolf-Waagen based in Upper Palatinate, Bavaria, Germany. Around since 2013.	http://wolf-waagen.de/neu/wp/stockwaage/
SolutionBee Beehive Monitoring System	Solutionbee LLC, based in Raleigh, North Carolina, U.S.A. Around since 2013. Solutionbee experts have decades of experience in designing and manufacturing communicating measurement products and systems used in outdoor environments involving extreme temperature and humidity in rugged conditions. Solutionbee delivers the highest quality beehive monitoring system in the industry. Our reliable, user friendly solutions enable both hobbyist and commercial beekeepers alike to optimize beekeeping operations. Our dedicated support team stands ready to assist in the set-up, maintenance, and use of the system to ensure you realize maximum value from your investment.	http://solutionbee.com/ http://www.brushymountainbeefarm.com/Hive-Scale/productinfo/714/
SmartBee Controllers	The SmartBee Control System is a real-time, remote-access solution for your greenhouse or grow room, monitored and controlled from the palm of your hand! Simply configure your environmental set points, and the SmartBee Controller's "smart logic" process detects problems, sends an alert, and automatically takes corrective steps to prevent and resolve critical grow room events! Wirelessly Networked Monitor & Control Solution by Swarm Technologies, based in the U.S. Around since 2014.	http://smartbeecontrollers.com/

Optibee	A beehive monitoring system by CAD Création, based in Puyoô, France. Around since 2014.	http://www.optibee.fr/index.php/en/
optilog-b Bienenstockwaage / Beehive scale XLOG bee	Professional hive scale system. A joint-venture project of Borntraeger GmbH based in Hesse, Germany and Micro El based in Zagreb, Croatia. Around since 2014/2015.	https://optilog-system.de/optilog-b-bienenstockwaage/
Bee Certain	Wireless Hive Monitoring System from Bob Barter of Bee Certain, LLC, based in Waldport, Oregon. Awesome engineering, published many details. Around since 2015.	https://www.youtube.com/watch?v=9XCGk_AvPNY http://bee-certain.com/ http://bee-certain.com/pages/technical-papers
BroodMinder – Bee Health Telemetry	A comprehensive monitoring solution from an agriculture company based in Stoughton, Wisconsin, U.S. Around since 2015.	http://broodminder.com/ http://app.beekeeping.io/ https://dl.dropboxusercontent.com/u/4212478/BroodMinder-User-Guide-for-V2_40.pdf
SmartHives BeeControlled	Smarthives is an online system, that supports beekeepers, who with the apiculture sector as well, gains significant benefits and progression in the everyday apicultural works. The system consists of an online interface and the sensors, which are connected to it. By György Wágner Senior and Junior, Görgy Fülöp, Gábor Kollár and Milán Bartalovics, based in Hungary. Around since 2015.	http://smarthives.eu/
Label Abeille	Bee Label, the connected beehive: a complete beekeeping monitoring system from an organisation based in Fleury-Les-Aubrais, France. Around since 2015.	https://www.label-abeille.org/gb/
Smart Hives	The beehive has remained nearly unchanged in 100 years. With the plight of the bees becoming a major concern we have developed a hive that aims to bring beekeeping to the masses. Waste pallets create the structure that is lined with wood fibre insulation to reduce the impact of the cold winter months on bee numbers.	http://somethingandson.com/smart-hives/

	Working in collaboration with a technology company it has integrated scales, thermometer and humidity sensing equipment linked to the internet to check and monitor the hive remotely. Over 50 hives have been distributed across the country aiming to make the life for both bee and beekeeper easier. By Something & Son. Around since 2015.	
EyesOnHives	Computer vision based Bee Hive Health Monitoring anytime anywhere. EyesOnHives is a camera and data platform for beekeepers' researchers & citizen scientists. By Keltronix Inc., based in Santa Barbara. Around since 2015.	http://www.keltronixinc.com/
APiS Technology	APiS Technology is a Portuguese startup based in Aveiro, that research, develop and sells products for sector of beekeeping. Bees are and always have been our passion. Our goal is to improve the way beekeepers take care of theirs. APIS Technology is the result of three years of development towards a solution that helps both bees and beekeepers. We are a multidisciplinary team with experience in electronic and software engineering, management and product design. Based in Aveiro, Portugal. Around since 2015.	http://apistech.eu/ https://www.indiegogo.com/projects/apis-tech-smart-hive-monitor-for-every-beehive/
Hive Genie Hive Monitor	By Mario Chapa of INGENUeering LLC, based in Montgomery, Texas, U.S.A. Around since 2015.	http://www.hivegenie.com/
WE GRO Funk Bienenstockwaage	Professional yet affordable hive scale system of WE GRO Engineering founded by Uwe Grotz based in Baden-Württemberg, Germany. Around since 2016.	http://www.we-gro.de/funk-bienenstockwaage/
Wi-Fi Hive Scale	From O'Keefe Electronics Inc. based in Ohio, U.S. Around since 2016?	http://wifihivescale.com/
Blazer	Blazer Technologies Ltd. is a company dedicated to using high tech hardware and software to save bees and digitize beekeeping. Based in Dublin, Ireland. Around since 2016.	http://www.blazer.buzz/

BEEing B Secure	Movement detection, and beehive tracking. Protects against floods, thefts and natural events. Around since 2016.	http://www.beeing.it/
BeeAndMe	Make the traditional beekeeping industry easier with tailormade hardware and software solutions. By Elma Hot and Alija Dervic, based in Vienna, Austria and Podgorica, Montenegro. Around since 2016.	http://beeand.me/
Apivox Auditor	This is a mobile application, for Android OS smartphones, which main task is - to turn your smartphone into a control and measuring instrument that allows you to receive and interpret acoustic data of bee colony, in order to understand its condition. Moreover, it allows obtaining and analyzing these data quickly and with a minimum effort. The application in its work, uses all possibilities of smartphone as a portable computer, which can collect and process data. The device receives acoustic data from the built-in microphone or wired microphone or Bluetooth headset operating in a microphone mode. APIVOX AUDITOR was created in collaboration between engineers and beekeepers, so it provides the configuration and functions that reduce errors and distortions of measurement results on the one hand and makes the use of device simple and effective for beekeepers on the other. Around since 2016.	http://www.apivoxauditor.com/

2.2 Evalution of additional sensor for the HIVE system

The HIVE system is also explicitly suitable for a wide range of other sensors and applications. In the following section possible extensions for the HIVE system are explained and discussed.

Flight board activity

The activity monitors of the flight board can be grouped according to the type of sensor and the variety of activities they can (potentially) monitor. The most common flight board activity monitors are video based. However, there is only one of these monitors on the market, Keltronix' EyesOnHives, and currently (2019) it can only monitor the general activity level at the entrance of the hive. The second type of input activity monitors is audio-based. An audio-based input activity monitor is available from Arnia. The third type of input monitors focuses mainly on foraging; it counts the bees entering and leaving the hive. Most bee counters somewhat interfere with other activities at the entrance panel, so their use is limited.

Accelerometer

Accelerometers are simple and cheap, and they can inform the beekeeper that a beehive has been knocked over by storm, bears, vandals or other causes, and they can send a message when a beehive is moved, which can be important if the movement is unexpected. Finally, the exact position of the beehive is an important data element in the beehive management software.

GPS

A GPS system can not only record the movement of the beehive, but also report the location of the beehive. This is a particularly important anti-theft feature. Knowing the location of the hives is also useful during visits, whether for inspections or for collecting the hives after a nectar flow or pollination event.

Infrared camera

A recent addition is the infrared camera. These usually combine the images from both a standard digital camera and an infrared camera so that the heat sources seen in the infrared image appear within the standard image, which is usually shown in outline. The use of infrared cameras in beekeeping is still being researched, but they are usually used to find the location of the winter cluster in the hive and to determine the exact position of a colony when a bee colony is removed from a building. The only organization for surveillance technology that offers an infrared camera is the Danish company BeeWatch.

Weather stations

As we well know, the weather influences the activities of bees. Whether it is the nectar and pollen production of the plants that affects the forage for these products, whether excess heat drives the foraging in the water collectors, or whether cold air or strong winds hinder any flight activity - the weather outside the beehive can explain many activities in the beehive.

Many colony monitoring system providers also place temperature sensors outside the beehive, often in conjunction with the beehive scale. Many of these external sensor sets also include a humidity sensor and some even a rain gauge. Still other suppliers take the approach of integrating data from a nearby weather station into the data display.

Feed monitoring

In the past, bees stored enough food in the form of pollen and honey for their own year-round use and usually stored a surplus for the beekeeper to harvest. However, modern agricultural and beekeeping practices often require bees to be fed. As they are fed, bees consume some of the feed and store some of it. The rate at which the feed is depleted provides only partial information. The correlation of feed data with data on hive weight and brood volume can be helpful.

At present, we are not aware of any electronic feed monitoring devices. The simplest such device would report when the feeder is empty. A more sophisticated device would report that the feeder is being removed from the feeder.

Manual recording of feed consumption data is the current option. The beekeepers can record the date of filling, the amount of feed and the date when the manger is found empty. If a container with graduated markings is used to indicate the amount consumed, a more detailed record of consumption can be made. If the bees do not consume the feed as expected, this may indicate a problem: the feed may have gone bad, a nectar flow may have started, the number of bees may have decreased, etc.

At low temperatures, it may be too cold for the bees to break up the clusters and reach the required food. It is vital for the survival of colonies to check whether wintering colonies can occasionally warm up naturally and whether the bees can break up the clusters to get to the honey, syrup or sugar patties. Measuring changes in hive weight and feed consumption rates is one way to determine whether colonies have been configured to allow successful hibernation.

Honey detector

The main components of honey are glucose and fructose. Continuous glucose meters have been developed for diabetics who need to monitor the glucose level in their blood. It seems plausible that these measuring devices could be adapted to detect the presence of honey in the parts of the hive intended for storing honey. A honey detector would help to unambiguously determine the weight sensor data, since both bees and honey contribute to the weight of the hive.

Honey is ripe when the bees seal the honeycombs. The sugars have been converted and sufficient water has been removed to prevent spoilage. Detectors for ripe honey located at the ends of a frame near the bottom beam could signal the readiness of a frame to harvest. And a honey monitor in winter storage facilities could warn when supplies are depleted.

It seems plausible that a detector for ripe honey in the cup or frame could be developed, although none has yet appeared. These could be based on the continuous glucose meters used by people with diabetes. There are numerous commercial continuous glucose meters available, including https://www.eversensediabetes.com and http://www.dexcom.com/.

Today, the annual cost of a continuous blood glucose meter to a human being is thousands of dollars, but as we know, the cost of the technology is decreasing rapidly, and while a honey sensor must be made of food grade materials, it does not have to meet the stringent standards required for human medical technology. Several methods are used in the laboratory for routine quality control of honey. A simple portable testing device could help prevent beekeepers from accidentally mixing "honey" made from sugar syrup or corn syrup with high fructose content with real honey made from nectar.

Pheromone detector

Odours in the beehive include bee pheromones, nectar from forage plants, disease odours and environmental odours. Each of these smells can tell us something useful about the condition of our beehives.

Bees communicate with each other by means of pheromones. The ability to monitor the bees' pheromone communication system would enable beekeepers to understand colony activity at a level never reached. Imagine if you knew the quality of the queen, the hunger of the brood or the presence of an alarming visitor in the hive. The chemical environment of the beehive is complex, perhaps too complex for a pheromone sensor system to exist soon. Nevertheless, the bees themselves can sense certain pheromones, and efforts to prove the concept, such as bovinosis, which monitors bovine pheromones, and other research on the "artificial nose", suggest that this task is feasible.

In addition to pheromones, the detection of nectar scents would inform the beekeeper about the nectar sources. If honey from certain flower sources leads to premium prices, this information would be useful to inform the beekeeper of the beginning and end of nectar flow and, like other sensors, could be particularly useful when his colonies are in remote locations.

Many bee diseases have specific odours, the smell of American foulbrood, for example, is well known, and the Maryland Bee Inspector has even trained a dog to detect it. The yeast of the small hive beetle also has a specific smell that an artificial nose could detect. Unfortunately, Varroa mites can mimic the scent of a honeybee's cuticular hydrocarbons down to the level of the individual colony, so they would evade a system for detecting E-noses (Varroa destructor changes its cuticular hydrocarbons to mimic new hosts) because they now avoid the bees.

Finally, environmental odours, such as the exhaust of the 2-stroke engine of a mosquito nebula or the diesel exhaust of an unexpected vehicle in the beehive or the track of a bear, etc., would also be useful information.

CO_2 sensor

Honeybees can sense the level of carbon dioxide (CO2) in the hive but not the level of oxygen, Seeley reported in 1974 in a paper titled "Atmospheric Carbon Dioxide Regulation in Honey-Bee (Apis Mellifera) Colonies". If the CO2 content rises above 1%, the bees fan out if they do not group to reduce it. A high CO2 content in the hive during brood rearing or nectar processing may indicate inadequate ventilation.

In contrast, bees in winter clusters apparently induce hypoxia in the cluster to reduce its metabolic rate, and the induced metabolic rate correlates inversely with the CO2 content (see "Hypoxia-controlled winter metabolism in honey bees (Apis mellifera)"). Consequently, a CO2 sensor placed in the cluster might be informative about winter cluster conditions.

Currently, there is no supplier offering carbon dioxide sensors for beehives.

Air pressure sensor

Ventilation of beehives is a very important but almost completely unexplored dimension of the behaviour of bee colonies and the interest in monitoring. For each of the three main activities of the bee colony (brood rearing, nectar processing and winter clustering) there is an optimal hive environment (temperature and humidity). The bees try to create and maintain these environments despite the external conditions and within the limits of the hive isolation and hive openings.

The amount of energy the bees use (i.e. honey consumed by the bees) to overcome suboptimal conditions in the hive for each of these main activities has never been determined. However, it has been calculated that about half of the nectar introduced into the hive could be consumed in the processing of the remaining nectar into honey. See: Thermal efficiency increases distance and diversity...

One must ask how much more energy bees use to overcome suboptimal hives. It would appear that a hive designed for optimal performance in any main activity would minimize the effort required to fan the hive for ventilation and minimize the energy needed to heat or cool the hive, thereby reducing the bees' effort and stress and increasing their health and productivity. The air pressure sensors used in toy quadcopter drones to detect changes in altitude could potentially be used in beehives to monitor air movement.

(source: https://colonymonitoring.com/)

3. Intended work plan of a follow-up project

Of a total project duration of 3 years, 2 years are planned for the continuous monitoring of the breeding populations. The initial phase of the project will be used to manufacture and commission the sensor system and to adapt the control software. During the 2-year measurement phase, detailed stock cards will be kept to record selection characteristics such as vitality parameters, varroa tolerance, reduced tendency to swarm and winter breeding. The focus of the last half year of the project is the correlation of the multi-sensor data with the beekeeper protocols (stock cards). With the help of AI-supported regression and classification methods the data will be evaluated. The project is divided into 5 work packages.

3.1 Workpackage 1: Structur of the Sensorsystem

AP1 includes all measures of installation/commissioning of the HIVE monitoring systems at different locations with 24 populations each

- Adaptation and production of HIVE monitoring units for a total of 72 breeding populations
- 1 HIVE control module is required per HIVE unit; each colony is equipped with 4 sensors (microphone, thermometer, hygrometer, scale)
- Provision of the solar power supply at the three locations
- Software adjustment (cont. measurements, local storage of data on SD card)
- Structure of the weather stations
- Commissioning and test operation

- Fenced locations are chosen to ensure protection against theft

3.2 Work package 2: Data collection

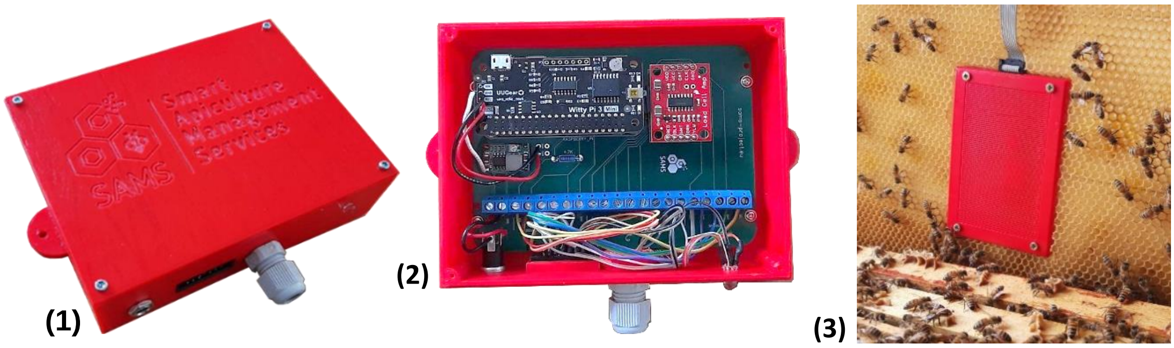

Figure 1: HIVE modular beehive measurement system (1), HIVE control module with connection of sensor frame and scale (2), sensor frame with microphone, thermometer and hygrometer for measurements inside the beehive (3).

AP2 is used for sensor data acquisition of breeding populations over 2 project years at three locations. Acoustic data, temperature, humidity and weight are continuously recorded for each colony. (Fig. 1). At each of the three locations, outdoor temperature and humidity are also recorded.

- Per site 6-8 Buckfast lines are monitored to ensure a broad genetic spectrum
- Sensor data is continuously written to SD cards, which are exchanged every 10 days
- All monitored colonies are equipped with an ID, through which all breeding information can be called up
- Weather data is collected per location

3.3 Work package 3: Apicultural protocols

All colonies equipped with the HIVE sensor system are regularly examined by a experienced beekeeper regarding the selection characteristics (varroa-sensitive hygiene, reduced tendency to swarm and winter brood) and recorded in detail.

- Every 10 days during the season from the beginning of March to the end of September protocols are made by trained beekeepers.
- Out of season, protocols are made every 20 days
- The stock card protocols and tests include the following parameters
    - Development
    - Popular strength
    - Varroa infestation (powdered sugar test)
    - Removal behavior of killed brood
    - Swarming mood

- Aggressiveness
- Yield
- Activity

3.4 Work package 4: Data exploration

In this work package the information gained from WP 2 and 3 will be combined. The sensor data will be correlated/classified with the breeding protocols using appropriate statistical methods. The aim is to find patterns in the multisensory data in order to statistically correlate them with the selection characteristics recorded and desired by the breeder.

- Transfer of the data into a suitable database
- Preprocessing of the data
- Multifactorial and multivariate evaluation using common methods (e.g. PLSR, SVM, Ensemble models); development of soft sensors
- Development of prognosis models for the early recognition of the desired characteristic value
- Identification of key parameters for selection feature recognition

3.5 Work package 5: Project-Management and dissimination

The project requires not only scientific and technical development work but also administrative activities and publication of the results in professional journals and breeders' conferences.

- Coordination and administration of the project, accountability reports for the funding agency
- Publications in scientific journals
- Presentation of the project at breeders' conferences
- Assignment of topics and supervision of student theses on partial aspects of the project

4. Prospects of success and exploitation of the proposed follow-up study

We are not aware of any work on sensory supported breeding approaches. Therefore, there is a considerable knowledge gap, which can be closed by the planned project. The follow-up project presented here is characterized by the fact that an optimized and faster breeding progress has a decisive leverage effect for the resilience of honey bees. A successful completion of the project allows the use of prognosis models regarding selection characteristics with reduced conventional control by the breeder. With the goal of strengthening the resistance and pollination performance of honey bees in the long term through breeding, beekeeping in Germany can be positively influenced. High winter losses, swarming tendency or ectoparasites do not only generate financial problems for the beekeepers, but above all reduce the pollination performance, which has extraordinary great economic benefits. Although it is difficult to quantify the prospects of economic success here, it can be assumed that breeding optimization has a decisive leverage effect. The University of

Kassel is not pursuing any economic goals with the follow-up project in agreement with SAMS open source philosophy.

5. Further application areas

The advantages mentioned in chapter 2.1, including expandability, modularity, recyclability, individualisation and remote maintenance, to mention a few, mean that the system can be used well in other areas. For example, schools, educational institutions and makerlabs as well as beekeeping associations and beekeeping associations can be considered here. The system is also very suitable for the field of science and research. For example, it is conceivable that the system could be used in other areas of the agricultural sector as a data logger with very precise time adjustment after some further development and in combination with a weather station.

- The Hive system is a very flexible sensor monitor system, which can also be used for other scientific questions. The system will be equipped with the appropriate sensors and the control software is adapted according to the requirements. An example could be the long-term measurement of nitrate contents of surface waters.
- The HIVE system can assist beekeepers in their breeding choices. With the help of sensor data, desired breeding traits can be detected earlier and more precisely (see chapter 1).
- There are existing projects which offer to adopt a bee colony https://www.planbeeltd.com/. Usually there is no direct access to the hives rented by the customer. With our HIVE monitoring system, customers could observe all relevant data (weight, flight activity, acoustics) in real time. An additional camera would also be possible here. The customers who rent a beehive can always observe their colony and there is a considerable added value compared to an anonymous sponsorship.

6. Standards

The following chapter describes standards for data and software code. The chosen open source licence is shown and BeeXML is presented instead of an unsuitable ISO standard as an appropriate way of standardised data exchange.

6.1 Open Source

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

MIT License

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6.2 ISO

The International Organization for Standardization (ISO) is the worldwide association of standardization organizations. It develops international standards across all sectors except electrical, electronic and telecommunications. Therefore, BeeXML was chosen as a suitable description of a standardized data format.

6.3 BeeXML - Exchanging Data about Bees and Beekeeping

In collaboration with partnership PS2: International Partnership on Bee Colony and Knowledge Exchange, BeeXML agreed to join the SAMS partnership and idea is to further work on a development of a BeeXML standard for the convenient bee colony data exchange process between scientists, beekeepers and other interested parties. Together we will exchange the information and evaluate the BeeXML document (under development) to check if all needed fields are there and maybe it is needed to update something based on the SAMS experience and data collection, storage process.

The BeeXML project is not about creating a central database. Rather, XML is a self-describing data format that can allow the exchange of data. It is about:

- Documenting the standard
- Documenting our implementation experiences
- Providing a beeXML Implementation Guide
- Collaboration with other standards bodies
- Providing assistance in properly understanding and interpreting the BeeXML standard
- Supporting all projects in their efforts to exchange of data about bees and beekeepers in a standardized format
- BeeXML.org is not an electronic market place or a software

The beeXML standard enables the following benefits:

- Accurate data

- Reduced costs for exchanging data between projects and institutions
- Consistent information throughout the beekeeping sector
- Interact between project partners in an uniform manner
- Simplify the process for dealing with multiple sources of data
- Reduced manual work, resulting in fewer entry errors
- Real-time exchange of information and greater electronic information availability

XML - (Extensible Markup Language) is used to store and transport data. Some design principles of XML:

- Simplicity: ease of usage, interoperability & understanding
- Modular design: do one thing well
- Extensible: Ability to easily modify the structure & content
- Self-descriptive: ease of understanding
- Machine readable
- Human readable
- Embedded descriptive tags

XML is designed for data availability, sharing, and transport. It requires complementary technology to do anything else. i.e. someone must write a piece of software to send, receive, store, or display it, for example:

- HTML: Format & presentation of the data
- Web Service: Transport of the data (e.g. SOAP)
- Database: Store & integrate with other data sources

(Source: http://beexml.org/, Data modeling for XML and Json)

The path to build a data standard includes the following steps.

- Survey Data Space: Surveying and mapping a data space by collecting samples of a large variety of data to identify collectible and viable data elements for evaluation, including a diversity of data from genetics, health, honey testing, and management practices, to name a few
- Data Prioritization: Identifying which types of data are most important to measure and which types have the most value to researchers and beekeepers now
- Measurement Scale: Deciding how best to measure those factors like health assessment, weights, treatment standards, Varroa counts, etc.
- Technical Architecture: Developing the technical architecture for storing, transmitting and analysing that data in a common format for computer-to-computer storage and harmonization
- Inclusive Governance Infrastructure: Following an inclusive and conscious approach both to govern the process and the output of the standardization in collaboration with

practitioners, researchers, Governmental Organizations and the International Organization for Standardization (ISO), in line with ISO's approach in other fields of research.

Current Challenges to Standardization

- Lack of Organized Data: It seems there is a near global lack of good recorded data related to bees and beekeeping, with 74% of respondents in one survey admitting that they do not keep records of their actions but instead rely primarily on memory.
- Data Format: For those who do keep records, most of it seems to be on paper, hive boxes or custom spreadsheets. If the data is not recorded digitally, in a standard format, it is difficult to collect.
- Data Quality: Outside of a few software systems and sensors, most data that is collected outside of rigorous scientific studies tends to have many contextual and data quality issues, making it hard to interpret and standardize.
- Proprietary: Of the data that is collected in a quality manner, such as by software companies, pharma, and some commercial beekeepers, much of it is considered proprietary and a competitive asset of the firm that owns it, which creates a reluctance to share.
- Technical Help: When we do receive or find useful data, it takes time and resources to convert that data to a conceptual standard, and even more to a technical standard, such as BeeXML.

(source: https://www.beeculture.com/the-promise-of-standardized-data/)

7. Data Transmission

Regarding data transmission, pre-conditions of existing ICT networks, especially in rural settings (GSM net coverage) are part of the report D3.6 [Report on data communication].

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