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Web Monitoring of Bee Health for Researchers and Beekeepers Based on the Internet of Things

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Abstract

The Colony Collapse Disorder (CCD) also entitled '*Colony Loss*' has a significant impact on the biodiversity, on the pollination of crops and on the profitability. The Internet of Things associated with cloud computing offers possibilities to collect and treat a wide range of data to monitor and follow the health status of the colon. The surveillance of the animals' pollination by collecting data at large scale is an important issue in order to ensure their survival and pollination, which is mandatory for food production. Moreover, new network technologies like Low Power Wide Area (LPWAN) or 3GPP protocols and the appearance on the market easily programmable nodes allow to create, at low-cost, sensors and effectors for the Internet of Things. In this paper, we propose a technical solution easily replicable, based on accurate and affordable sensors and a cloud architecture to monitor and follow bees' behavior. This solution provides a platform for researchers to better understand and measure the impacts factors which lead to the mass extinction of bees. The suggested model is also a digital and useful tool for beekeepers to better follow up with their beehives. It helps regularly inspect their hives to check the health of the colony. The massive collection of data opens new research for a better understanding of factors that influence the life of bees.

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Keywords: precision beekeeping; precision agriculture; lambda architecture; colony collapse disorder; Internet of Things; bee health

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1. Introduction

The pollination industry represents a market of 153 billion € per year[1]. The production of 75% of global fruits, vegetables and seed crops rely on animal pollination, which represents 35% of global food production[2]. Honey bees are important crop pollinator which plays a significant role in the ecological system and the industrial crop. Honey bees is a good indicator of pollinators' health[2]. These pollinators are now increasingly at risk of extinction because of their natural predators, climate change and new threats resulting in massive disappearance of bee colonies.

The Colony Collapse Disorder (CCD) is caused by multiple well-known factors such as the use of pesticides in agriculture, the presence of pollutants in environment, mite infections (i.e. *Varroa jacobsoni* recently renamed *Varroa destructor*), fungal diseases (i.e. *Nosema ceranae*), viruses (i.e. Deformed Wing Virus or Acute Bee Paralysis Virus), climate changes and malnutrition and starvation linked to environmental degradation[2,3,4,5,6]. Other researchers have shown the interaction effect of multiple stressors, both abiotic and biotic, on CCD such as viruses with parasitic and multiple pesticide interaction etc[4]. Beekeepers must also protect their colony against external aggression such as Asian hornet (*Vespa velutina sp*), European hornet (*Vespa crabro sp*), Wasps (*Vespula vulgaris sp*) and natural predators such as mouse and woodpecker. Moreover, they must also manage natural process of swarming. The swarming is highly stochastic and natural process during which the old queen leaves the colony with a group of worker bees to base a new colony in a new place at few kilometers of the original place where the rest of the colony stay with the new queen[9]. The unmanaged swarming affects the profitability of beekeeping. The hive colony are generally placed at several kilometers of the headquarters and requires the use of remote monitoring systems.

The surveillance of colonies by collecting a wide range of data around the world from both beekeepers and research centers is a cornerstone to understand all the mechanisms responsible of CCD and their interactions. The understanding of all the mechanisms implicated in CCD, help protect pollination insects and ensure their survival and guarantee the food production. The studies on health status of pollinators are done in research centers and/or universities in isolation by researchers. The monitoring of colony requires affordable and durable equipment that are easy to place. These data are coming from multiple origins such as punctual observations, images, videos, sounds and time series, etc. In the past monitoring of honey bee activity was monitored manually but it was not possible to catch the behavior of hundreds of bees in and out of hives[10]. To solve this issue researchers have developed automatic and effective systems to monitor bees' behavior. The use of sensors in precision agriculture is becoming widespread especially in precision beekeeping also named precision apiculture. Indeed, the technology of Wireless Sensor Network (WSN) has largely been used by beekeepers and many researchers to monitor especially ambient conditions in the hive, detect swarming or count entering and exiting of bees. The Internet of Things associated to cloud computing offers possibilities to monitor and follow health of honey bee colonies. Data can be automatically collected and sent to a gateway at a given time. Moreover, the large availability of a large range of Low Power Wide Area (LPWA) or 3GPP protocols and the appearance on the market of cheap and easily programmable nodes such as Pycom[†] microcontrollers allow today to achieve, at low-cost, sensors and effectors for the Internet of Things.

In this paper, we propose a chain of tools to measure different parameters in hive and easy to deploy which supporting multi protocols of communication. We suggest and describe a new infrastructure allowing to collect, store, treat and share information between scientists. The sharing of important amount of data is necessary to create a robust model and re-validate existing models. The proposed lambda architecture brings benefits in storage, real-time processing and abilities for large scale data storage and analytics.

2. Literature review

Zacepins et al. in 2015 have listed what should be remotely detected at colony level: development status of bee colonies, diseases, CCD, all events which may require beekeeper's action such as pre-swarming and swarming state, extreme nectar flow, queenless state, broodless state, dead colony, starving and first cleaning flight in spring. To achieve these aims, data must be collected at different scales. At macro scale (in the apiary) meteorological parameters such as temperature, relative humidity, light, wind speed and rainfall must be acquired at real-time with a

[†] http://www.bienenwaage.de/englisch/beehivescales.html

meteorological station. Video recording may be used while a disturbed factor for apiary is detected by a microphone or motion detector. The use of the video is particularly expensive in term of energy and cannot be used continuously. At meso scale (in the hive) the meteorological parameters are temperature, relative humidity, O_2 and CO_2 rate, contaminant gases (Nitrogen Dioxide, Ethanol, Ammonia, Carbon monoxide, Methane, etc), video, vibration of the hive and weight. At micro scale (bee individually), the number of entering and exiting bee, the number of bees in the hive entrance area[7].

Researchers have used temperature measure in the hive in one or several points to try to detect the increasing of food consumption, the start of brood rearing, the pre-swarming states or the death of the colony. The hive weight monitoring is used to detect the start and the end of nectar flow during the foraging season and to measure daily nectar storage. Otherwise, the variation of the hive weight allows to measure the consumption of food during non-foraging periods, estimate the number of foragers and indirectly the fecundity of the queen. Weather factors such as precipitation, relative humidity, hours of sunshine and wind can affect weight data[14]. Finally, the occurrence of swarming events can be correlate with the decrease of the hive weight. The weight can be automatically measure by weighting systems such as, BeeWatch[‡], CAPAZ[§] or WiFi Hive Scale[**]. Bees in a hive produce vibration frequencies comprised between <10 Hz to >1000Hz[14]. Vibration, Audio signals and processing techniques allow to predict event such as swarming period. The sound of flying bees near the beehive entrance can also be used to evaluate the productivity of the hive. The discrete Fourier transform can be applied to audio signal in order to represent the data as a sum of a series of sinusoidal waves of varying frequencies and amplitudes. Vibrations and sound data can analyze using Principal Components Analysis (PCA) or analyze the amplitude of few frequency band[14].The monitoring of vibrations of external wall of the hive allow to predict the swarm several days in advance. According to Ferrari et al., 2008, the level of spectral power density of pre-swarming is approximately at 110 Hz. While the swarming, the amplitude and the frequency of sound increase at 300 Hz with a dramatic change between the bandwidth from 150 Hz to 500Hz[13]. Dioxygen and Carbon dioxide are involved in the metabolism, but the automatic measure need controlled air flow and the microclimate of the bee nest may influence them. Beekeepers and researchers must regularly check the sittings of the microclimate of the bee to make sure that they are not other elements that would interfere with the air movement across the sensor like propolis or wax. In addition to that, the video is placed in the main entrance of the hive to monitor its conditions[14]. The Bee counting can also be achieved by mechanical or electronic devices appeal bee counters. The most popular bee counter is the BeeScan[††] is sophisticated precision scanner which use 32 channels of detection to measure the entering or exiting bees.

The literature abounds in terms of bee monitoring systems. Among the most remarkable contributions are those of Edwards-Murphy et al. who proposed a monitoring system based on heterogeneous WSN which measures with two nodes carbon dioxide (CO_2), dioxygen (O_2), Nitrogen Dioxide (NO_2), Ethanol (CH_3CH_2OH), Ammonia (NH_3), Carbon Monoxide (CO) and Methane (CH_4), temperature, relative humidity and acceleration. The data transmission is ensured by a base station ZigBee/3G[11]. Although this approach is interesting, it remains dependent on the availability of 3G. In addition, the ZigBee protocol is a short-range protocol (about ten meters) which only supports a limited number of nodes. Jiang et al. in 2016 have worked on a system of counting of bee entrance and exiting based on infrared led detection. The proposed system uses the WSN technology and measure also temperature and relative humidity in and out of the hive[10]. The data that acquired at hive level are transmitted to a gateway which transfer them to a backend platform by GPRS. Kridi et al. used a WSN and temperature sensor measure of microclimate in the hive and compare it with thermal pattern in 2016. Moreover, the data that acquired one time per hour are transmitted by XBee pro 900HP which offer better performance than Zigbee protocol allow to detect anomalies[8]. Gil-Lebrero et al. in 2017 have built a Remote Monitoring System based on Waspmote and measure in multiple point temperature in hives. The architecture in three level has been proposed with communication using IEEE 802.15.4 protocol for local communication and 3G/GRPS, WiFi or WiMax for communication between local database server and global database

‡ http://beewatch.de/

§ http://www.bienenwaage.de/englisch/beehivescales.html

** http://www.wifihivescale.com/

†† http://users.telenet.be/lowland/beescan2101.pdf

server. This architecture provides a local direct access which keeps the system functional in case of long distance telematic link breakage[12].

Kviesis et al. in 2015 have compared advantages and disadvantages of five different architectures for the real-time monitoring of bee hive[15]. The first approach consists to consult data directly in the apiary. In the second approach, the data are sent to a computer located in the apiary by a wireless protocol which treats locally data or send them to remote computational center. The third approach consists to delegate data acquisition to a microcontroller such as Arduino or a microcomputer such as Raspberry Pi which transfer data by Internet to a database or a remote computational center. The fourth approach use the direct send of data from sensors or via a gateway to a remote computation station. For the he fifth approach, data are analyzed directly on nodes and sent to the beekeepers.

The massive collection of data, at planet scale, and their sharing require a cloud storage platform to standardize, secure, store, treat, control the access and allow the exchange of data.

3. System architecture

The fourth approach proposed by Kviesis et al.[15] will be used to deploy the wireless network sensor. This way directly allows nodes connection on one or more LoRa/Sigfox gateway or use a LTE-M protocol to transmit data directly in Internet on wide area.

In this paper, we use a data transmission multiprotocol microcontroller LoPy, but others more recent model such LoPy4[‡‡] and FiPy[§§]can also be used. These microcontrollers do not cost much money, easily programmable in micro python and embed natively several protocols where other microcontrollers such as Waspmote[***]need extension board to add the support of supplementary protocols. The principal characteristics are given in Table 1.

Table 1. Principal characteristics of PyCom microcontroller

Characteristics	WiPy 3.0	LoPy 1.0	SiPy 1.0	LoPy4	GPy 1.0	FiPy 1.0
Support of WiFi	Yes	Yes	Yes	Yes	Yes	Yes
Support of LoRaWan	No	Yes	No	Yes	No	Yes
Support of Sigfox	No	No	Yes	Yes	No	Yes
Support of Bluetooth	Yes	Yes	Yes	Yes	Yes	Yes
Support of LTE (cat 1/NbIoT)	No	No	No	No	Yes	Yes
ADC 12 bits/DAC 8 bits/GPIO	8 / 0 / 24	8 / 0 / 24	8 / 0 / 24	8 / 0 / 24	8 / 2 / 22	8 / 2 / 22
Ram / External flash	4Mb/8Mb	512Kb/4Mb	512Kb/4Mb	4 Mb/8Mb	4Mb/8Mb	4Mb/8Mb
Price HTVA and hotport	19.95€	29.95€	34.95€	34.95€	44.00€	54.00€

These microcontrollers are equipped by a Dual Processor Espressif ESP32 chipset, a hardware floating point acceleration, support hash/encryption SHA, MD5, DES, AES and is provided of 2 UART, SPI, 2 I^2C, I^2S, micro SD card and a Real Time Controller (RTC) at 32.768Hz. The deep sleep mode consumption is only of 10 µA and the hibernation mode 1µA. Furthermore, all these microcontrollers weigh only 7g and support SSL/TLS and WPA enterprise.

LoPy4 and FiPy microcontrollers make it possible to adapt to the main networks of the Internet of Things according to their availability. The meteorological station transmit data each minute by one of the four IoT protocols. In case of using Sigfox, due to a protocol limitation to 140 messages sent by day, the data can only transmit every ten minutes.

Temperature and relative humidity of the air are measured in the hive with a AM2315 sensors I^2C (address 05C) with a high accuracy providing an error of ±0.1°C for temperature and ±2% for relative humidity. Temperature in the brood is measure in 4 points using SHT35 (Sensirion). The I^2C sensors SHT15 (addresses 0x44 or 0x45) are protected

‡‡ https://pycom.io/product/lopy4/
§§ https://pycom.io/product/fipy/
*** http://www.libelium.com/products/waspmote/

by enclosing in perforated queen expedition cages Nicot® as suggested by Gil-Lebrero et al. to ensure that the sensors will not be covered by wax and propolis by the bees. They are connected to the I^2C bus of the microcontroller by mean of an I^2C multiplexor TCA9548A (Texas Instruments). The air quality I^2C sensor (address 0x76 or 0x77) is a BME680 (Bosch Sensortec) which measures gases with a precision of 2% for Carbon Monoxide and 5% for Ethanol. An LSM303DLHC (STMicroelectronics) accelerometer compass measures vibration in the hive. The hive is also equipped with a tilt sensor to detect accidental overturning of the hive and a contact sensor to detect the opening of the hive. The system uses IP67 enclosure which guarantees reliable performance in a dusty environment and protection against the effects of immersion up to 1 meter deep. The power consumptions of sensors and microcontroller is done in Table 2.

Table 2. Power consumption according to manufacturer's data and interface of connection

Component	Interface	Operation mode	Supply Current (Max)	Voltage
SHT35[†††]	I^2C	Sleep / Measuring / Average	1.5 µA / 1 mA / 28 µA	5 VDC
AM2315[‡‡‡]	I^2C	Sleep / Measuring / Average	15 µA / 0.5 mA / 0.3 mA	5 VDC
BME680[§§§]	I^2C	Measuring / Standby / Sleep	12 mA / 0.29 µA / 0.15 µA	3.3 VDC
LSM303DLHC[****]	I^2C	Normal / Sleep	0.11 Ma / 1 µA	3.3 VDC
TCA9548A[††††]	I^2C	Normal / Standby	8 µA / 0.1 µA	5 VDC
LoPy		On / Deep sleep / Hibernation	10 mA / 10 µA / 1 µA	5 VDC

The meteorological weather uses a temperature and relative humidity sensor AM2315 (Aosong), a barometric sensor BMP 280 (Bosch) and a weather meter SparkFun to measure wind speed, wind direction and rainfall. A microcontroller LoPy transmit data on LoRaWan. The architecture of developed nodes is illustrated in Figure 1.

Data from Hive nodes and the weather station are sent using LoRa frequency modulation to one or more LoRa gateway available in the area which transfer data to the Things Network (Free LoRaWan Network). Then, data are forwarded from The Things Network to own cloud architecture. The LoRa/LoRaWan protocol is a robust to interference protocol using the spreading factor, double AES 128 bits encryption. This protocol is also allowed to connect more thousands of nodes on a unique gateway which are distributed in a perimeter up to 15 km around the gateway. This protocol uses ISM Frequency band and offers the possibility to send a payload up to 242 octets.

As shown in Figure 2, the proposed cloud architecture consists of two parts: First, a lambda architecture which is able to collect and store different kinds of data and keep the structure easily adaptable[16]; second, a scientific sharing platform which shares data applications and models between all the research teams. The use of containers and virtualization technologies make it easy to deploy different versions of the same model and validate them on a wide range of data.

Moreover, the technology of containerization also allows a continuous integration of change made on the model and a rapid deployment. In this architecture proprietary and real-time data are treated by streaming processing. Event and time related data are treated by batch processing which consists of data verification (complete and consistent data). If data are incomplete or erroneous, they can be corrected, and erroneous or missing data must be also interpolated. Each corrected or interpolated data is specifically tagged "corrected" or "generated data" in order to differentiate them from the original data. This architecture is adaptable to many cases and has already been tested by Debauche et al. in 2017 for the cattle behaviour[17] and the digital phenotyping[18]. The streaming process can also treat image and streamed data such as video and sound data.

[†††] Temperature and RH sensor
[‡‡‡] Temperature and RH sensor
[§§§] Environmental sensor
[****] Accelerometer
[††††] Multiplexor I^2C

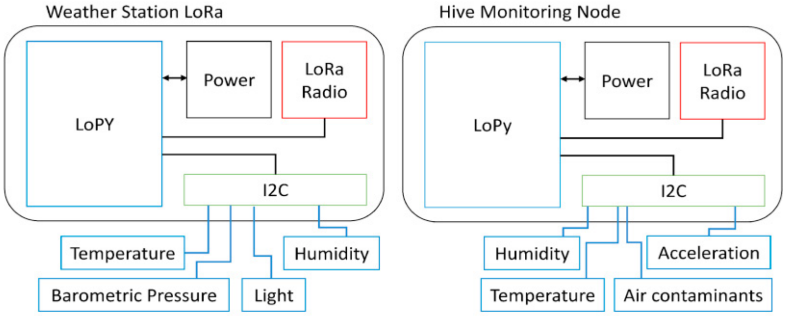

Fig. 1. Architecture of developed nodes

In the lambda architecture, Apache Kafka provides a message bus between nodes and Apache Samza. Yarn containers run Apache Samza to preprocess data by eliminating erroneous or incomplete data that improve by ten the speed of data ingestion by Druid. Druid is a distributed fault tolerant column-oriented database which is composed of four types of nodes designed to ingesting and exploring large amount of times-stamped data. The unit of storage in Druid is "segment" composed of 5 to 10 million times-stamped data compressed with LZ4 and covering a time period. In our architecture, Druid uses a PostGresSQL database to store metadata of segments. A quorum of Zookeeper monitors the four kinds of Druid nodes present in the cluster. These four nodes respectively coordinate, broke, store in real-time or archived data on HDFS[‡‡‡‡]. Real-times nodes provide functionality to ingest, query, index event streams for small time range. Indexes are maintained in-memory to be directly queryable. A background task merges indexes together and build immutable blocks with ingested data from real-time nodes. Segments are then uploaded to HDFS. Historical Nodes contain functionalities to load and serve the immutable block of data created by real-time nodes. Brokers nodes route incoming queries to historical or real-time nodes and return a final consolidated result to the applicant. Brokers nodes contain a caching system with a LRU[19] invalidation strategy and using Redis to store key-value. Finally, Coordinators nodes are in charge of data management and distribution on Historical nodes: loading, dropping, replication and moving of data.

The scientific sharing platform uses Apache Mesos and Docker containers to isolate and host applications. Mesos isolation is better than Docker but we have mixed both for compatibility reasons. A quorum of Zookeeper: one master node and two master standby nodes ensures fault tolerance in the cluster. Mesos offers several pluggable frameworks. Each framework sends tasks to the master node which transfer them to Mesos slave executor available. When the task is executed the result is sent to node master which forward them to the framework. Docker slave node can host external application which do not initially developed to work on frameworks plugged on Mesos. They can nevertheless be hosted with container technology offered by Docker.

4. Experimental results

In the experiments related to this study, we measure the impact of data compression at the sensor level. Data compression consisted in eliminating the redundant data while keeping the original ones. We apply a protocol in which all the redundant data are replaced by a time interval during which the value remains constant in order to keep the data integrity.

The implementation of the lambda architecture and fog computing on the LoPy reduce the data amount that must be transmitted to the LoRa gateway and the bandwidth used. The compression algorithm proposed in this paper improves storage efficiency in the distributed database hosted in the cloud. The compression of the data reduces also the battery consumption. Indeed, sending data is the operation that consumes the most energy. Two strategies were compared: the first one sending data only when they change and the second one is compressing and sending them each ten minutes. During a week, we calculate the results, in a local scale, by applying both approaches and comparing them with a third strategy, which is sending the data without compression. The analysis of compression rate shows

[‡‡‡‡] Hadoop Distributed File System

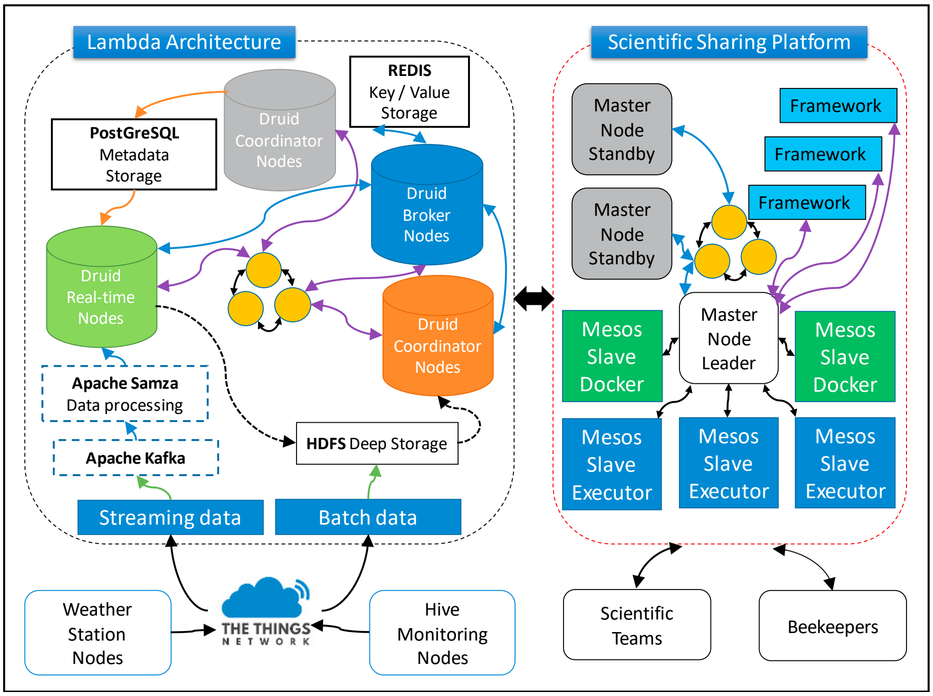

Fig. 2 Proposed Architecture

that the compression of data reduces the bandwidth consumed for their transmission to the gateway by an average of 72%. The reduction of the battery consumption obtains by the first mode of compression is 12% and the second mode of compression is 8%.

Our solution acquires at high frequency a more accurately meteorological parameter in order to detect their microvariations as proposed by Zacepins et al. in 2015[7]. More accurate measures impact directly the detection of swarming. Lora consumes less energy than other protocols proposed by other authors like Zigbee[11], GPRS[10] for the transmission of data. Furthermore, Lora support more devices than Zigbee which limited to 255. However, other protocol such as Xbee Pro 900 HP propose by Kridi et al. in 2016[8] could be an alternative to LoRa.

5. Conclusion and future work

In this paper, we propose a new data storage architecture dedicated to scientific research. This lambda architecture is able to ingest a large variety of data at high frequency such as images, videos, punctual data and time series data, etc. The main novelty of this architecture offered by this platform resides in its capacity to normalize, share and exchange data between group of researchers. Moreover, the increasingly wide availability of Internet of Things protocols such as LoRaWan, Sigfox, allows to transfer, at low cost, wide range of data from many different sources. The use of interference-resistant and robust protocols empowers the use of monitoring system in difficult conditions such as urban environments (urban beekeeping).

In future works, we will implement the NB-IoT protocol which depend of cellular network, propose a better throughput which will allow the transmission of more parameters and does not require the deployment of a specific technological network like the LoRaWan or SigFox.

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