Multi-sensor platform for real time measurements of honey bee hive parameters

S. Cecchi¹, A. Terenzi¹, S. Orcioni¹, S. Spinsante¹, V. Mariani Primiani¹, F. Moglie¹, S. Ruschioni², C. Mattei², P. Riolo², N. Isidoro²

¹ DII - Università Politecnica delle Marche - Italy
² D3A - Università Politecnica delle Marche - Italy
E-mail: s.cecchi@univpm.it

Abstract. Honey bees (Apis mellifera L.) are well-known insects that have positive effects on the environment and on the human life. They are so important that the decline of honey bee colonies happened in the last years has triggered an increasing interest for their safeguard. In this context, the proposed work aims at developing a multi-sensor platform to monitor the beehives’ conditions in real time, based on the measurement of sounds emitted by the bees, temperature, humidity, CO₂, weight inside the beehive, and weather conditions outside the hive. In this paper, a detailed description of the multi-sensor platform is reported and its application in a real scenario is presented.

1. Introduction
The importance of honey bees is not limited to the production of honey, beeswax, royal jelly, and propolis, because they are at the basis of the plants’ pollination, and play a key role in the proliferation of both spontaneous and cultivated flora. Recent years have witnessed an increase in bees’ mortality which can result in a loss of pollination services, with remarkably negative ecological and economic impacts that could significantly affect the maintenance of wild plant diversity, the wider ecosystem stability, and the crop production. The causes can be found in illnesses, like the Colony Collapse Disorder (CCD) which is characterized by a sudden disappearance of honey bees from the hive [1, 2]. Many bee scientists agree that the decline of honey bee colonies is the result of multiple stressors, acting independently, in combination, or synergistically to impact honey bees’ health [2, 3]. Starting from the above-mentioned context, the necessity of an intensive monitoring activity of honey bees emerges clearly, in order to understand the problems and the causes of bees’ mortality.

Monitoring sounds inside the hive is very important, since sound is used by bees to communicate within the colony. Sound generation by a bee takes place through several mechanisms: body movements, wing movements, high-frequency muscle contractions without wing movements, and by pressing the thorax against the substrates or another bee. A strict relation between sound characteristics and some events within the hive, like swarming or the presence of the queen bee, has been already proved [4,5,6].

Temperature and humidity are important parameters to measure inside and outside the hive, since they influence the bees’ health, the brood, and the productivity of the beehive. Several
studies have been carried out on this topic showing that a correct temperature and humidity can significantly decrease the mortality rate in the colony and can increase the honey production.

Carbon dioxide (CO$_2$) measurement is another important aspect since it is related to the bees’ metabolism. In particular, metabolic heating of a bee normally accompanies a change in the respiratory emission of CO$_2$. As the carbon dioxide within a colony in the hive can reach much higher levels than the normal atmospheric ones, honey bees use fanning and gas exchange events to expel CO$_2$-rich air, and to keep the CO$_2$ at an acceptable level [7],[8],[9].

Finally, regularly weighing the hives can provide useful information on the changes over time in the main biological components of honey bee colonies [10], i.e., adult and brood populations and food stores[11],[12]. Weighing honey bee hives often provides precise information on timing and size of events such as swarming and unforeseen hive phenomena.

Starting from the aspects presented above, a multi-sensor platform [13] has been designed and implemented, considering two different modules, in order to have several satellite boards on each hive, and a single master for one colony. The system is capable of acquiring in real time sounds, temperature, humidity, CO$_2$, and weight inside the beehive, and weather-related data outside the hive. All these parameters are strictly related to the bees’ health status and they can be used to analyze and to forecast critical and possibly dangerous situations. The system has been installed in real bee hives and it will be used to collect a complete dataset of the aforementioned parameters.

The paper is organized as follows. Section 2 describes the hardware platform development, considering the selected sensors and their physical deployment. Section 3 details the software platform and the functions developed to evaluate the measured values. The deployment of the multi-sensor platform in a real scenario, and the related issues, are reported in Section 4, showing the behavior of some measured parameters. Finally, conclusions are reported in Section 5.

2. Hardware platform for data acquisition

The hardware platform is composed by two different modules, in order to have a set of satellite boards (called Bee Boards, one for each hive) and a single master board (called Queen Board) for one colony. Figure 1(a) shows a schema of the Bee Board module installed in each hive. The module is capable of recording signals from input sensors, i.e., sound and microclimatic parameters. The sensors are positioned inside the hive in a way that they result as less invasive as possible. This is an important aspect to avoid some issues such as the covering of the sensing devices with propolis by the bees, as they usually do with every foreign body entering the hive [14].

For sound acquisition, two microphones are installed in each hive. MEMS (Micro Electro-Mechanical Systems) microphones have been chosen in order to keep the whole system as hidden and smaller as possible. In particular, the chosen model is the Analog Devices ADMP401 [15], featuring a bandwidth between 100 Hz and 15 kHz. Signals from the microphones are acquired by a 24 bit USB sound card, connected to the Raspberry Pi and providing a sample rate of 32 kHz.

In order to acquire temperature and humidity data, the DHT22 [16] sensor has been chosen, being a low cost and small one-wire digital sensor. Each hive is equipped with three DHT22 sensors, two inside the hive for data acquisition, and one located near to the electronic board for system health monitoring. Regarding temperature, each sensor features a measurement range from $-40^\circ$C to $80^\circ$C, with an accuracy of $\pm0.5^\circ$C and a resolution of $0.1^\circ$C. Moreover, relative humidity is measured in the range $[0 \div 100] \%$Rh with an accuracy of $\pm2\%$Rh and a resolution of $\pm0.1\%$Rh.

For carbon dioxide, the Telaire TL6615 [17] sensor has been installed. It is realized in Non Dispersive Infrared (NDIR) flow-through technology. The TL6615 can measure in the range $[0 \div 50000]$ ppm with an accuracy of 75 ppm on 10% of reading, generating an analog output
from 0 V to 4 V, which is acquired by a Texas Instruments ADS115, an I^2C Analog to Digital Converter (ADC), capable of 16 bit resolution and a sample rate of 860 Hz.

Finally, the weight is measured by means of four SparkFun weight sensors. Each sensor is an analog load cell with a flow of 50 kg [18], connected to the other cells in a Wheatstone bridge configuration. The bridge output is acquired by an HX711 [19] 24 bit ADC specific for weighting application.

The embedded data collection platform is managed by the central processing unit, i.e., a Raspberry Pi 3 Model B programmed on purpose, that acquires data generated from each input sensor. Figure 2 shows the hardware housing, consisting of the Raspberry Pi, the sound card, the analog interface to the sensors and the power supply.

Figure 1(b) shows the overall scheme of the master module that collects the data related to weather conditions and manages the data generated from each hive. The module is installed near the colony and communicates with each hive over a TCP/IP connection. The master also connects the entire system to the outside world through a wireless high-speed Internet connection supported by a point-to-point radio link implemented with MikroTik SXTG-5HPnD-SAr2 antennas . This way, a PC server is directly connected to the bee colony, running a software developed ad hoc to manage all the acquired data. The software moves the data from the mass storage of each bee hive into the server, and allows the real-time visualization of the data, through a graphical interface.
3. Software components in the data acquisition platform
The software components necessary for the data acquisition platform have been developed using two programming languages: the Raspberry Pi acquisition code has been written in Python 2.7, while the server tasks for data visualization and data storage have been implemented using LabView 2016. Focusing on the Python script, the code reads data from each sensor every five seconds; sensor data are written in .csv file and sent to the remote server for real-time visualization, over a TCP connection. Moreover, exploiting the functionalities of PyAudio and the Advanced Linux Sound Architecture (ALSA) driver, sounds from the hive are recorded continuously, and saved every ten minutes on .wav files. At the server side, different LabView Virtual Instruments (VIs) have been developed. Figure 3(a) reports a screen shoot of a VI that shows in real-time the data acquired from each bee hive and received through the TCP connection, i.e., temperature and humidity, weight and CO₂ values. Figure 3(a) shows a screen shoot of a VI that acquires data from the weather station i.e., temperature, humidity, atmospheric pressure, UV-light, visible light, infrared light, rain wind intensity and wind direction. Finally, Figure 3(c) shows a screen shoot of a VI that allows a preliminary sound analysis on recorded data, by means of Fast Fourier Transform (FFT). During the data acquisition process, ad-hoc script move data from each Raspberry Pi internal storage to a remote Network Attached Storage where data are saved and available for analysis.

4. A case of study
The system has been deployed in the field, to monitor a colony composed by three hives positioned within the University Campus. Figure 4 shows the installation of the system with a Bee Board module deployed in each hive and the Queen Board module, equipped with the weather station sensors, and the antenna for the radio communication to the remote server. The data recording started in 2017, June 15th; until now, 17 TB of data have been acquired. Particular events with a great relevance for the bees’ health have been annotated in the database, such as the death of the queen bee, bee hives diseases, and the presence of the Varroa mite. Figures 5(a) and 5(b) show sample data acquired from the microphone of one hive, over a period of 10 minutes, in time and frequency domain, respectively. As reported in [13, 6], the sound can vary in several situations, e.g., when the queen bee is dead or in a warning condition. Future works will be oriented to the development of an automatic procedure for real-time sound analysis and event detection. Figures 5(c) to 5(f) show the variation of CO₂, weight, humidity and temperature during one day. An evident correlation among all the parameters appears:
Figure 3. Graphical user interface of the software developed for real-time monitoring and data acquisition. In particular: (a) visualization of the Queen Board data together with micro climatic parameters, (b) visualization of the data generated by each Bee Board (one virtual screen for each hive), (c) visualization of the sound emitted by a selected hive, in time (top screen) and frequency (bottom screen) domain, in arbitrary units (a.u.).
Figure 4. In the field deployment of the Bee Board modules and the Queen Board module.

during the day most of the bees go outside and there is a reduction of the hive’s weight, of the CO$_2$ and of the temperature, going to the detriment of the humidity. Future works will be oriented to a joint analysis of these parameters, as a function of the sound generated within the bee hives.

5. Conclusions
In this work, a multi-sensor platform capable of real-time monitoring beehives condition has been presented. Such a system has been developed to record the sounds emitted by the bees in the hives, and also other measurable parameters such as temperature, humidity, CO$_2$, hive weight and weather conditions. A real deployment of the system in the field has been described, joint with an overview of the preliminary results obtained from the measurement campaign that is going on since 2017. Future works will be oriented to the development of tools for automatic data analysis and event detection, aimed at a better understanding of the conditions affecting the bee colony’s health status.

References
[1] J. Faucon, L. Mathieu, M. Ribire, A. Martel, P. Drajnudel, S. Zeggane, and et al., “Honey bee winter mortality in france in 1999 and 2000,” Bee World, vol. 83, pp. 14–23, 2002.
[2] B. Oldroyd, “Whats killing american honey bees?,” PLOS Biol, vol. 5, 2007.
[3] D. Van Engelsdorp, J. J. Hayes, R. Underwood, and P. J.S., “A survey of honey bee colony losses in the united states, fall 2008 to spring 2009,” J Apic Res., vol. 49, pp. 7–14, 2010.
[4] D. Dietlein, “A method for remote monitoring of activity of honeybee colonies by sound analysis,” Journal of Apicultural Research, vol. 24, no. 2, pp. 176–183, 1985.
[5] S. Ferrari and et al., “Monitoring of swarming sounds in bee hives for prevention of honey loss,” in International Workshop on Smart Sensors in Livestock Monitoring, Sep. 2006.
[6] A. Qandour, I. Ahmad, D. Habibi, and M. Leppard, “Remote beehive monitoring using acoustic signals,” 2014.
[7] G. Nicolas and D. Sillans, “Immediate and latent effects of carbon dioxide on insects,” Annual Review of Entomology, vol. 34, no. 1, pp. 97–116, 1989.
[8] E. Southwick and R. Moritz, “Social control of air ventilation in colonies of honey bees, apis mellifera,” Journal of Insect Physiology, vol. 33, no. 9, pp. 623 – 626, 1987.
[9] T. Seeley, “Atmospheric carbon dioxide regulation in honey-bee (apis mellifera) colonies,” Journal of Insect Physiology, vol. 20, no. 11, pp. 2301 – 2305, 1974.
[10] W. Meikle, N. Holst, G. Mercadier, F. Derouan, and R. James, “Using balances linked to dataloggers to monitor honey bee colonies,” Journal of Apicultural Research, vol. 45, no. 1, pp. 39–41, 2006.
Figure 5. Sample data acquired from the hive sensors: (a) sound in time domain (sampling frequency: 32 kHz), (b) sound in frequency domain, (c) CO$_2$ inside the hive, (d) hive weight, (e) relative humidity and (f) temperature in the hive.

[11] A. McLellan, “Honeybee colony weight as an index of honey production and nectar flow: A critical evaluation,” *Journal of Applied Ecology*, vol. 14, no. 2, pp. 401–408, 1977.

[12] J. R. Harbo, “Worker-bee crowding affects brood production, honey production, and longevity of honey bees (hymenoptera: Apidae),” *Journal of Economic Entomology*, vol. 86, no. 6, pp. 1672–1678, 1993.

[13] S. Cecchi, A. Terenzi, S. Orcioni, P. Riolo, S. Ruschioni, and N. Isidoro, “A preliminary study of sounds emitted by honey bees in a beehive,” in *Audio Engineering Society Convention 144*, May 2018.

[14] S. Gil-Lebrero, F. Quiles Latorre, M. Ortiz, V. Snehe Ruiz, V. Gamiz, and J.-J. Luna-Rodriguez, “Honey bee colonies remote monitoring system,” *Sensors*, vol. 17, p. 55, 01 2017.

[15] “Admp401 mems microphone.” https://www.analog.com/media/en/technical-documentation/obsolete-datasheets/ADMP401.pdf.

[16] “Dht22 temperature humidity temperature sensor.” https://www.sparkfun.com/datasheets/Sensors/Temperature/DHT22.pdf.

[17] “Telaire t6615 co2 sensor.” https://www.amphenol-sensors.com/en/telaire/co2/525-co2-sensor-modules/319-6615.

[18] “Sparkfun 50kg load sensor.” https://www.sparkfun.com/datasheets/Sensors/loadsensor.pdf.

[19] “Hx711 weight scale adc.” https://www.mouser.com/ds/2/813/hx711_english-1022875.pdf.