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Implementation of an electronic system to monitor the thermoregulatory capacity of honeybee colonies in hives with open-screened bottom boards

Víctor Sánchez [a,b], Sergio Gil [b], José M. Flores [b,*], Francisco J. Quiles [a], Manuel A. Ortiz [a], Juan J. Luna [a]

[a] Department of Computer Architecture, Electronics and Electronic Technology, University of Córdoba, Campus of Rabanales, 14071 Córdoba, Spain
[b] Department of Zoology, University of Córdoba, Campus of Rabanales, 14071 Córdoba, Spain

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ABSTRACT

Electronic systems are not widely used for measuring biological variables in beehives despite the importance that honeybees have for both the environment and humans. A better understanding of bee colonies is needed in order to prevent certain dangers that threaten the bee population. In this study, we have developed an electronic system based on the Arduino Open Hardware platform, to which we have added temperature and humidity sensors to adapt the system to the particular conditions of beehive management. The system has been used to record changes in temperature and humidity inside hives and assess bees' thermoregulation adaptability within colonies in hives with opened-screened bottom boards; an interesting management tool for controlling the harmful *Varroa destructor* mite as compared to beehives with conventional closed bottom boards. The results revealed that bee colonies were able to thermoregulate in hives with open anti-Varroa bottom boards to the same degree as those in conventional bottom board hives even under winter conditions in a mediterranean climate, thus indicating that there are no additional risks associated with the use of open-screened bottom board models.

1. Introduction

Measuring physical parameters such as ambient temperature and humidity is a common task in industrial applications. Although many commercial systems known as data loggers have been specifically designed for data acquisition, caution is required when applying such systems to biological processes.

Recent developments in electronics and computing technologies have enabled the study of many biological processes. For example, remote-sensing techniques can be used to investigate the movement of insects in the field and in the laboratory (Reynolds and Riley, 2002). As regards honeybees, computer equipment has been used for various purposes, such as recording sounds from bee colonies and relating them to different functions, such as swarming, colony requeening and bee health (Woods, 1958; Dietlein, 1985; Ferrari et al., 2008; Atauri and Llorente, 2009; Bencsik et al., 2011; Eskov and Toboev, 2011; Zacepins et al., 2011; Zacepins and Karasha, 2013) or monitoring hive weight (reviewed by Meikle and Holst, 2015). However, the monitoring of temperature and humidity in bee colonies have been most widely studied. Dunham (1931), for example, measured the temperature inside a beehive using thermocouples. Since then, many studies have associated beehive temperature and humidity with other factors, such as brood distribution, the influence of external temperature, and swarming or displacement of the colony inside the hive (Dunham, 1931; Kronenberg and Heller, 1982; Fahrenholz et al., 1989; Chuda-Mickiewicz and Prabucki, 1996; Stalidzans et al., 2002; Vornicu and Olah, 2004; Human et al., 2006; Meitalovs et al., 2009; Abou-Shaara et al., 2012; Zacepins and Karasha, 2013; Rice, 2013; Stalidzans and Berzonis, 2013; Meikle and Holst, 2015). Like other branches of agriculture, precision beekeeping is currently being developed in the field of apiculture through the electronic monitoring of bee colonies in order to achieve maximum productivity from the hives and consume fewer resources (Zacepins et al., 2015).

Honeybee colonies are regarded as superorganisms (Moritz and Southwick, 1992) with certain capabilities reserved for higher organisms, such as colony thermoregulation. As such, there is much interest in the regulation of beehive temperature and humidity. Bees warm the nest by shivering their flight muscles and clustering above the cells, particularly the brood cells, which need higher and more stable temperatures. Conversely, bees can lower the nest temperature by fanning their wings to generate air currents and remove

* Corresponding author.
E-mail address: ba1flsej@uco.es (J.M. Flores).

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moisture from the hive. They often have to bring water to the hive to later evaporate it (Lindauer, 1955; Simpson, 1961; Southhwick and Moritz, 1987; Kühnholz and Seeley, 1997; Bujok et al., 2002; Stabentheiner et al., 2003; Human et al., 2006).

Temperature and humidity must remain stable to ensure the proper development and survival of bee colonies as an imbalance in these factors can produce disorders or diseases such as chalkbrood caused by the fungus *Ascosphaera apis* (Bailey, 1967; Flores et al., 1996; Abou-Shaara et al., 2012). Environmental conditions also have a direct influence on the effort the bees must make to maintain these factors constant or to adapt to climate changes. Imbalances within the beehive may also be caused by handling by the beekeepers. Therefore, it is important to understand these factors inside the beehive.

An example of the above occurs when using hives with open-screened bottom boards to prevent infestations by the deadly *Varroa destructor* mite. Hives with this type of floor are open to the exterior via the lower surface, allowing the mite to fall through the mesh. These screened floors are very effective in removing mites from the colonies and reducing Varroa populations (Pettis and Shimanuki, 1999; Harbo and Harris, 2004; Delaplane et al., 2005; León et al., 2011). However, it is uncertain as to how screened boards affect bees' ability to regulate temperature and humidity within the beehive, especially during the winter season, when a cooling of the colonies could trigger diseases such as chalkbrood.

The aim of this study was to develop an electronic system to record temperature and humidity inside beehives and use these data to assess the adaptability of honeybee colonies in hives with opened-screened bottom boards compared to hives with conventional closed bottom boards.

2. Material and methods

2.1. Electronic system implementation and data processing

For the collection of periodic data regarding temperature and humidity, an electronic system especially designed to adapt to the internal conditions of a beehive was created. Fig. 1 shows the block diagram of the designed data collection and processing system where several blocks can be distinguished:

1. Sensor and amplification system. This system is responsible for transforming physical magnitudes into electrical signals. Two types of sensors are used: (i) Sensor *LM35 by National Semiconductor* (see http://www.ti.com/lit/ds/symlink/lm35.pdf), which generates an output whose voltage value is proportional to the temperature, with a ratio of 10 mV per each Celsius degree. The output signal of the sensors is amplified so as to obtain a 0.1 °C accuracy within the range from 0 °C to 50 °C. (ii) Sensor *SHT15 by Sensirion* (see http://www.sensirion.com/fileadmin/user_upload/customers/sensirion/Dokumente/Humidity/Sensirion_Humidity_SHT1x_Datasheet_V5.pdf), which measures the value of the temperature by means of a band-gap sensor and the relative humidity through a capacitive sensor, with an error of ±0.3 °C as regards temperature and ±2% as regards relative humidity.

   The data are collected and requested through an I^2C based series interface known as Sensibus. The implementation of the communication protocol has been carried out by means of software using two I/O pins of the microcontroller.
   Due to the distance between the data collection and processing system and the different measurement points, we decided to place an amplifying stage close to every sensor. In this way, the signal noise relation is improved and a signal which is more insensitive to interference is sent. Fig. 2 (LM35 sensors) shows a photograph of the sensor and of the amplification stage within a protective cage.

2. Real-Time Clock (RTC) to place each measurement within a time context. As RTC, the integrated system DS1307 by Maxim Integrated (see http://www.datasheets.maximintegrated.com/en/ds/DS1307.pdf) has been used.
3. Massive data storage module, which has a 4 GB class 4 Flash SD card (Kingston) which is connected to the control and processing unit by means of an SPI interface. The application used 150 Kb/month, so each card could store two years of data.
4. Timing. It has a time selecting block to select the interval between measurements. It is a switch which is connected to several digital input pins of the control and processing system, which was designed to select the following intervals between measurements: 15 s, 30 s, 60 s, 5 min, and 15 min. Besides, the system is able to show the temperature and humidity inside the beehive in real time through an USB connection between the device and a PC. This is particularly useful when handling techniques are applied on the beehive. For this purpose, a Java language application, developed in Eclipse IDE Kepler service release 1, is used. This application also corrects the small variations in the RTC, allowing the synchronization of the different systems inside each of the colonies.

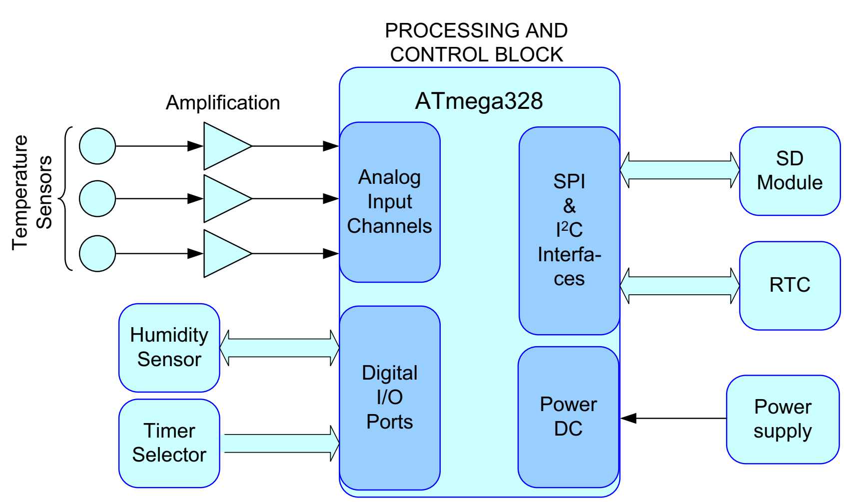

Fig. 1. Diagram of the data acquisition and processing system.