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A Monitoring System for Carbon Dioxide and Humidity in Honeybee Hives †

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Abstract: Two of the most relevant gasses correlating to honeybee colony health are likely carbon dioxide and humidity. Non-Dispersive Infra-Red (NDIR) detectors have become the dominant method for measuring atmospheric CO_2. In this work we describe a microcontroller-based system used to collect data from two models of these NDIR sensors that also provided humidity and temperature data. Placement in a frame in the brood box and in the crown board and queen excluder are investigated. With several thousands of hours of data for comparison, we demonstrate both the daily and long-term trends in these important gasses in multiple honeybee colonies.

Keywords: honeybee; carbon dioxide; humidity; Non-Dispersive Infra-Red; NDIR; SCD30; SCD41

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1. Introduction

Carbon dioxide has long been known as a narcotic for the honeybee and has been used to immobilize them during scientific manipulation or transfer [1]. Higher levels of exposure cause permanent damage or result in death, and it is believed that high CO_2 concentrations in the hive initiate fanning behavior [2]. For calibrated CO_2 measurement, the nondispersive infrared (NDIR) sensor is the closest sensor to meeting the requirements for hive installation. The basic principle is that an infrared (IR) source, closely matched to the absorption frequency of CO_2, shines down a sample tube containing air. The nondispersive terminology comes from there being no grating or prism to select the frequency of light rather, at the end is a filter to remove other frequencies followed by an IR detector. The difference between the amount of light radiated by the IR source and amount of IR detected is directly proportional to the number of CO_2 molecules in the air sample in the tube. Suitable models include the Sensirion SCD30 [3] which also includes temperature and humidity, the Teledyne T6713 [4] and the Sensair sunrise [5]. A lower cost alternative is the Wisen MH-Z19B [6] but this does not include an i2c interface. Most recently the Sensirion SCD41, using photoacoustic NDIR sensing principle, delivers a much smaller footprint sensor [7]. These devices are also not instant 'plug and play' for calibrated measurements as, on first use, access to 'outdoor' concentrations are often required as burn in to give accurate readings. However, once running these devices do give actual CO_2 gas concentration in parts per million within their specified error margin typically 30ppm + 3%.

Water vapor is water in its gaseous state and water vapor in the air is called humidity. More often reported as relative humidity, this is the ratio of the partial pressure of water vapor to the equilibrium vapor pressure of water at a given temperature. Temperature and humidity are two of the most important factors affecting the health and survival of honeybee colonies. Humidity is known to play a vital role in the development of brood.

Investigations into the effect of humidity were initially made possible by controlled laboratory incubators with more recent data being collected from hives in the field with smaller embedded sensors [8–12]. The measurement of humidity is readily available in low-cost small capacitive sensors that provide a relevant level of accuracy and in analogue or digital formats. Digital devices usually include temperature measurement in the same package and reduce measurement errors by undertaking the analogue to digital conversion on the sensor chip rather than introducing possible noise in the measurements.

In this article we investigate the use of the Sensirion SCD30, and later the SCD41 for application in honeybee hives as these provide a specified CO_2 measurement range up to 40,000ppm, with a specified accuracy up to 5,000ppm, in addition to providing humidity and temperature data.

2. Materials and Methods

The data logging system chosen was the Teensy 3.5 microcontroller as this provided a real time clock and microSD card reader on board. The gas sensors were connected via the i2c bus to the Teensy 3.5 and a switch on one digital pin to allow the measurement to stop whilst the microSD memory card was safely replaced. Data, consisting of EPOCH time, CO_2, temperature, and humidity, were saved with around three measurements per minute to approximately one file per day on the uSD card. An initial system, based on the SDC30 gas sensor, was installed on a frame of an observation hive using a British National hive brood box at NTU campus in Nottingham and also comprised of an additional SCD30 to the top of the hive (above the crown board). When they became available, a new SCD41 sensor was installed alongside the top SCD30. A separate system was also installed on a different colony on NTU campus with the SCD41 sited in the queen excluder. These three positions allowed an investigation into the most appropriate positioning of sensors to be carried out, especially due to challenges of propolis coating of the sensors.

Figure 1a shows the SDC30 installed in a fully populated frame with a protective wire mesh cage covering it. Over time the bees fill the holes in the mesh with propolis and/or wax and these need to be cleared as part of the regular bee keeping. Figure 1b shows the SDC30 (lower) and SCD41 (upper) with a cm rule to provide a scale. Both types of sensors have been delivering hundreds of hours of data.

Figure 1. (**a**) SCD30 installed in brood box frame showing propolis coating on the protective mesh. (**b**) SCD30 (lower) and SCD41 (upper) sensors with rule to show relative sizes of the two devices.

3. Results

Figure 2 shows data from the SCD30 installed in a frame of the NTU observation hive. The top left graph is CO_2 from September 2021 when the colony was active on the frame, and this is demonstrated by the corresponding temperature data shown in the graph below being initially around 36 °C. Sharp peaks on the early CO_2 data show the need for the high temporal resolution that we are using

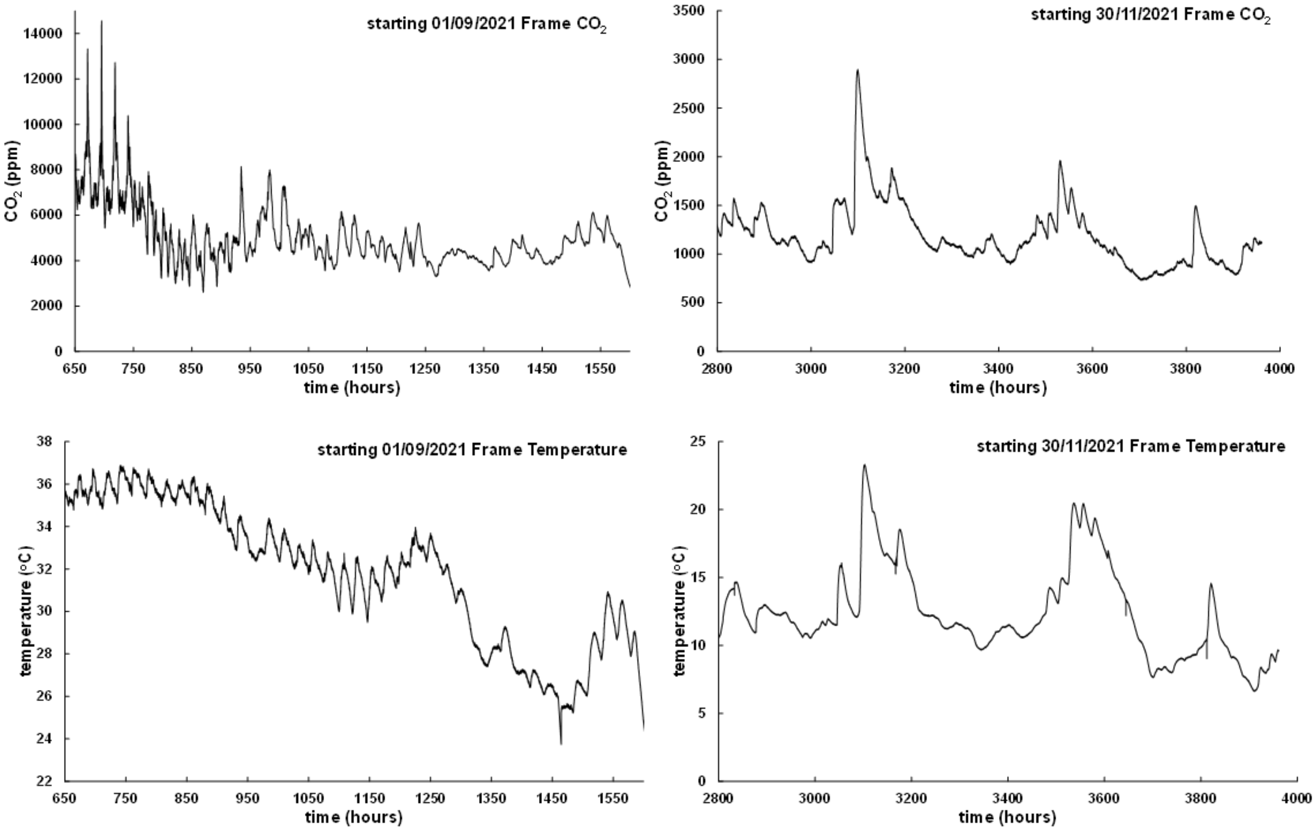

Figure 2. The top left panel shows the CO_2 in a brood frame over a thirty-seven-day period starting at the beginning of September 2021 with the panel below showing the corresponding temperature. The top right panel shows the CO_2 for the same frame starting at the end of November with the corresponding temperature below.

The top right graph is CO_2 from the end of November 2021 when the colony was no longer active on the frame, shown by the temperature graph below exhibiting typical ambient temperatures. The hive CO_2 level is still significantly elevated compared to outside 'fresh air' which is typically only 450 ppm.

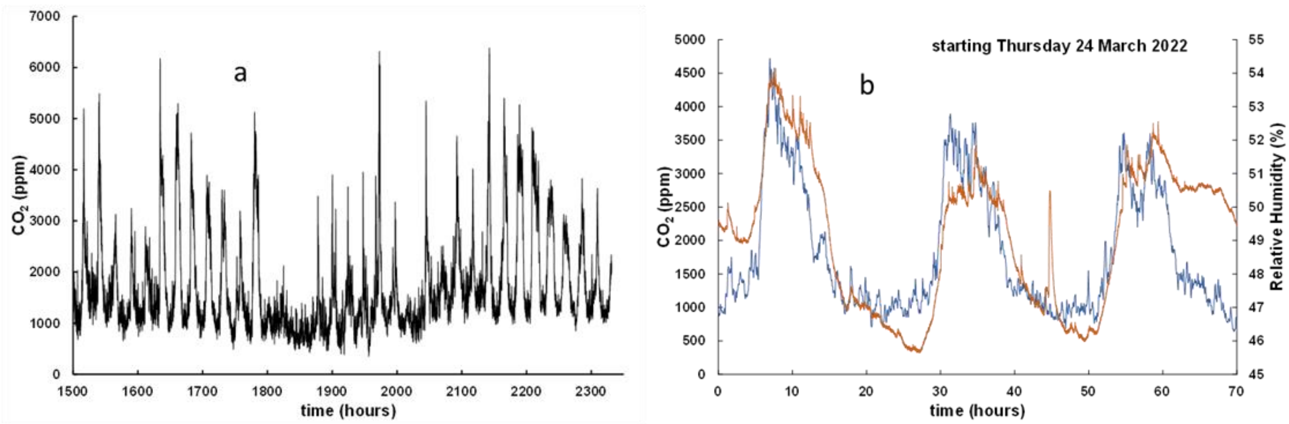

Figure 3. (**a**) CO_2 measured using an SCD41 in the crown board of the observation hive over a thirty-seven-day period starting in March 2022 exhibiting a clear daily variation; (**b**) CO_2 (blue line) and corresponding relative humidity (orange line) over a three-day period showing them following similar daily change.

4. Discussion

All positions of the SCD sensors provided high temporal resolution data showing both daily and longer-term trends in both CO_2 and humidity. Two distinctive features can be seen from all the data. Firstly, there is a significant daily variation in CO_2 and secondly the peak levels in the hive are ten times that conducive to human health. Even at the lowest values of CO_2, the data was far in excess of the values that would be conducive to human health where humans would expect general drowsiness between 1000–2500 ppm and adverse health effects may be expected from 2500–5000 ppm. In the frame, the maximum of 14,000 ppm is probably most reflective of the true levels of CO_2 that the workers experience on a brood frame. This maximum is within the range reported by Seeley [2] but much lower than values required to cause anaesthesia [1]. The paper by Cecchi et al. [13] used a Telaire TL6615 NDIR sensor installed directly in the wood panel of the brood box positioned in the lower part of the back side. Their data demonstrated a maximum of 3500 ppm suggesting that they were collecting data similar to our crown board sensor but much lower that the data from the frame sensor.

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Conflicts of Interest: The authors declare no conflict of interest

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