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A Spatially Resolved Temperature Measurement System for a Honeybee Colony Brood Box [†]

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Abstract: Honeybee colonies depend on suitable temperatures for successful development. We demonstrate the use of a spatially resolved temperature measurement system for a honeybee colony by producing ten custom frames which results in to four-hundred and eighty sensors across the hive. A first prototype used four layers of wax to embed the sensors, however, the honeybees rejected these and removed the wax before building new, irregular, honeycomb. A second system using a single sheet of wax onto which the sensors were laid was accepted by the colony, normal honeycomb was built. We showcase some of the data collected from this system.

Keywords: honeybee; honeybee health; temperature; spatially resolved temperature measurements

1. Introduction

Honeybee colonies are dependent on suitable temperatures for healthy colony development [1–4], including maintaining 32–35 °C to enable brood to develop [2].

Many studies investigating temperature inside a beehive have done so using a single sensor which is placed in or around the hive [1,3,5], for example, at the centre of the colony to monitor for brood rearing temperatures [1,3]. Other investigations have placed the sensor above the hive to detect changes in temperature relevant to the colony [3,5].

Choosing a single location to place a temperature sensor is inexpensive and simple but has a major disadvantage in that the highly localized measurement will often be a poor indicator of the entire colony's status [6]. As such, placing a sensor at the centre of the hive may be the optimum position to measure temperatures consistent with brood rearing, however, the colony does not necessarily fill all the available volume at its centre. Similarly, a sensor placed at the periphery of a hive will have measurements affected by external temperatures, which will usually be considerably different to those experienced by the colony centre.

A number of studies have investigated temperature variation across a honeybee colony [2,5–8,13], including over a short time period using thermal imaging to produce heat maps of the colony nest [7] and at several locations to detect differences in temperature between the colony centre, the periphery, the edge of the hive, and the outside [3].

Using an array of thermocouples laid onto a frame is a potential solution that has been proposed fifty years ago [8]. However, implementation of such a measurement system for spatial variation in temperature on a frame is still at a very early stage and has only been trialed modestly [13]. Obtaining a highly reliable measurement using such a

setup would constitute a major step forward towards furthering scientific understanding of how a colony develops [1,2,4,5] or how a colony uses a beehive at different points in time [2,5,7].

Temperature sensors are readily available and inexpensive in the form of negative temperature coefficient thermistors [10]. These thermistors work by exhibiting a resistance. An increase in temperature reduces the resistance and lower temperatures result in a higher resistance. It is well known that honeybees will propolise anything alien which is placed in the colony [6]. However, similar thermistors have been used before and their performance remains unaffected by propolisation [3]. As such, these thermistors are highly appropriate and can be soldered into a grid and used to measure temperatures at multiple locations.

We investigate the use of an array of negative temperature coefficient thermistors in a honeybee colony brood box to collect spatially resolved temperature measurements.

2. Materials and Methods

The spatially resolved temperature measurement systems used negative coefficient temperature thermistors [9] to collect data from the hive. The quoted resistance of the Littlefuse 104JG1F thermistors is 100,000 Ω and the resistance tolerance at 25 °C is 1%, the temperature coefficient at 25 °C is −4.4%/°C and the temperature range is −55 to +300 °C.

We used a British National hive and adapted it with ten customized brood frames. Each frame had a grid of forty-eight thermistors which were connected to three sixteen-channel analogue multiplexers [10]. Each multiplexer could handle sixteen inputs, and this dictated that forty-eight sensors was the maximum amount of sensors per frame.

The sensor array was laid out evenly with each thermistor being 3 cm away from another in all directions. The multiplexers handled the successive reading of each sensor it was connected to and the outputs were connected to a Teensy 3.5 microprocessor [11]. Each Teensy has twenty-seven analogue input pins which could handle nine frames. However, the hive has ten frames, as such, two Teensy 3.5 s were used to accommodate five frames each.

The Teensy 3.5 s were programmed to read the resistance of the thermistors in sequence, calculate the temperature, and send it to a Raspberry Pi [12]. The Raspberry Pi automatically reads the serial COM port data and saves every measurement and its corresponding timestamp to a file for further processing.

At the end of each day, a separate Octave software processes the temperature data collected into 5 min averaged values, to daily CSV files and figures which are saved and emailed to the researchers.
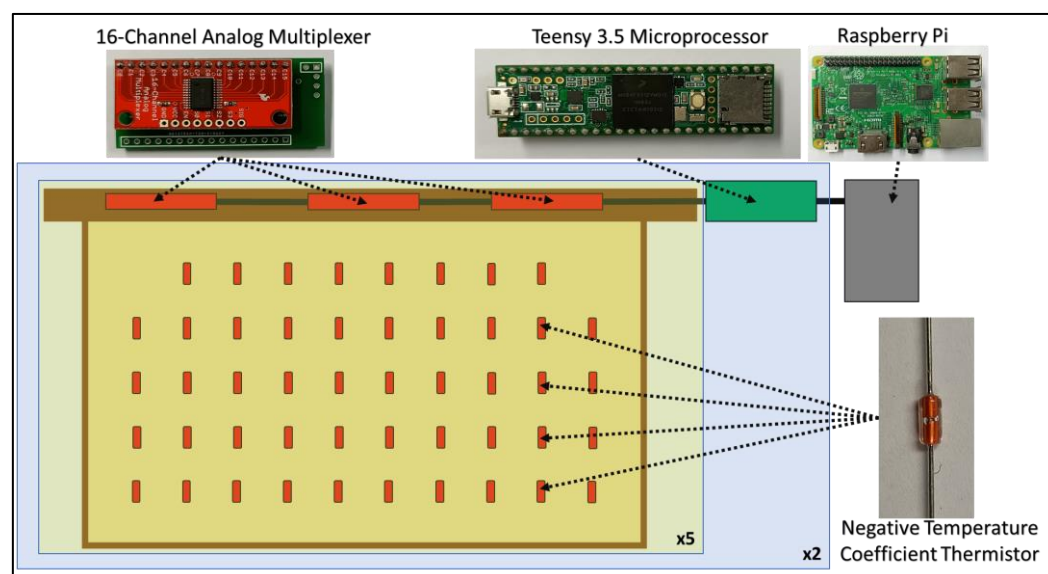
Figure 1. A scheme to demonstrate the hardware used to gather the spatially resolved temperature measurements from a honeybee colony brood box. Ten customized brood frames, each equipped with forty-eight negative temperature coefficient thermistors were built. Each frame is connected to three, sixteen-channel analogue multiplexers and the resulting voltage is further digitized with two Teensy 3.5 microcontrollers. Temperature data is sent to a Raspberry Pi which automatically saves the data with the current time stamp. Once setup, the system runs autonomously.

Two spatially resolved temperature measurement systems were produced, the first prototype was ready for tests with live bees in March 2021. This system had the sensor array embedded between four layers of foundation wax, in order to place the sensors deep inside the structure, well away from bees access, and to make the frames more appealing to the bees. The first system was installed at Holme Pierrepont Hall and was populated with a colony in May 2021. However, the honeybees rejected the frames, exposing the electronics before building new honeycomb.

The second system was tested in April 2022 and it used a single sheet of foundation wax ($\cong$1 mm thick) onto which the sensor array was laid. This system was installed at Nottingham Trent University Clifton Campus and was populated with a swarm in May 2022.

3. Results

The second spatially resolved temperature system was tested in April 2022 and data was collected for several days before a colony was introduced. The sensors showed consistent measurements across the hive and displayed a small error in line with the manufacturer's quoted tolerances and coefficients. Figure 2 displays the temperature recorded by all sensors on a single day at two separate times. The recorded temperatures are consistent and reflect the ambient temperatures.
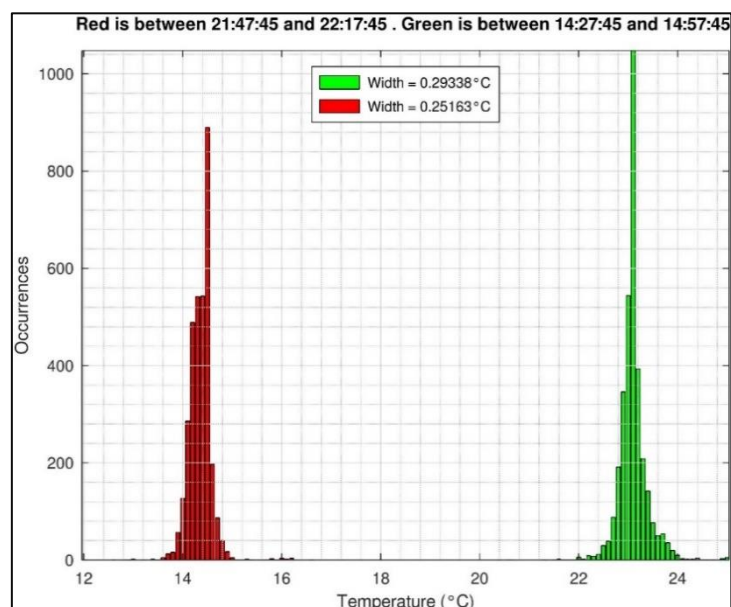

Figure 2. Temperatures recorded across all sensors in the system at two different times measured before the hive was populated with honeybees on 30 April 2022. This demonstrates the consistent measurements across all four-hundred and eighty sensors. Data has been linear scaled to compensate for systematic errors.

Figure 3 demonstrates the rejection of the first spatially resolved temperature measurement system and the acceptance of the second. The first system suffered from the bees chewing away the foundation wax, exposing electronics, before new honeycomb was built. The second system was accepted by the colony, which built honeycomb over the

sensors, embedding the thermistors, and allowing spatially resolved temperatures to be taken of the colony developing normally.

Figure 3. Inspection photographs from the spatially resolved temperature measurement systems. (**a**) A frame in the first system on 21 September 2021 showing rejection by the colony which has chewed away foundation wax thereby exposing the electronics. (**b**) A frame at the centre of the box on the second system on 18 May 2022 showing acceptance of the frames with the sensor array, having built fresh honeycomb over the top of sensors and the cells being used for brood rearing.

Highly valuable temperature data was collected across all frames from the second colony with examples provided in Figure 4. Honeycomb has been built on frame 5 and our system records temperatures around 35 °C on that day, reflecting the use of this frame for brood. Frame 3 has not been used, yet, by the honeybees and the data reflects this.
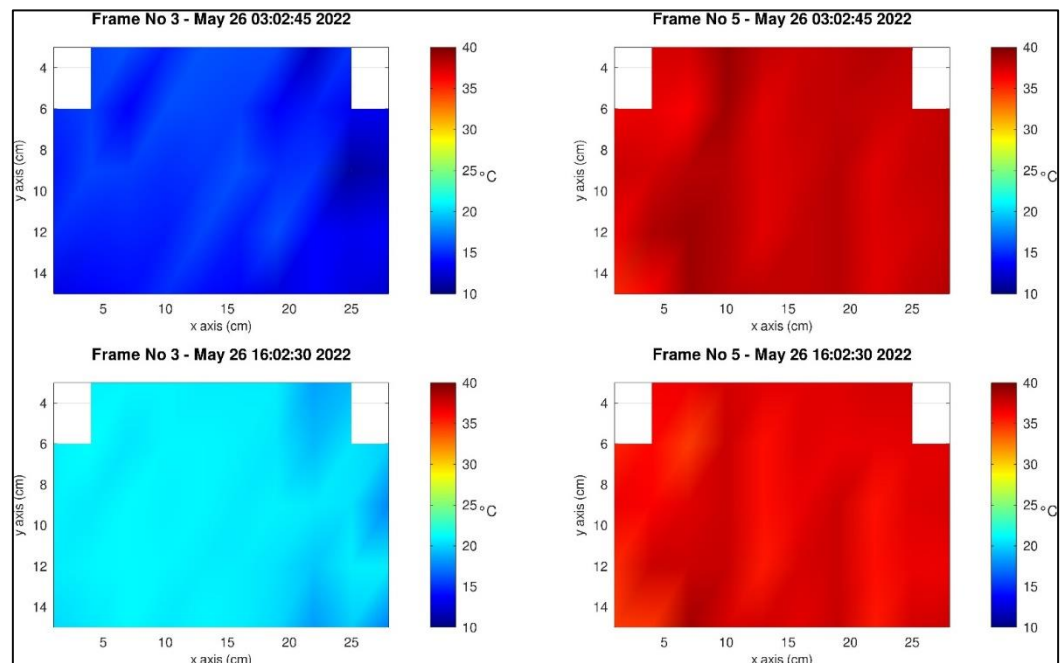

Figure 4. Demonstration of the spatially resolved temperature measurements recorded from the second system. Depicting temperatures recorded by sensors on frame 3 and 5 on May 26 2022. The colony has built honeycomb on frame 5 and the sensors measure high temperatures around 35 °C at any time of the day, consistent with the frame being used for brood rearing. Frame 3 has not had honeycomb built, yet, and it is not being used for honey or brood, and exhibits large variations at different times of the day. In addition to the detection of temperatures commensurate with brood rearing, the figure demonstrates the spatial variation in temperatures on both frames.

Additionally, Figure 4 displays the temperature variation detected from across a single frame. Frame 5 has patches of warmer temperatures with other areas exhibiting lower

temperatures, this is seen at both timepoints. The temperature of Frame 3 was much lower, closer to 10–15 °C at 3 am and around 20 °C at 4 pm. Again, the temperature varies across the frame with some sections being colder than others.

4. Discussion

The system provided spatially resolved temperature data with 480 reliable individual measurements across a brood box which captured variations in frame temperature. Distinctive features recorded include detection of brood rearing temperatures and the spatial variation in temperatures. Detecting these features with high spatial resolution is an important step to furthering our understanding of colony development [1,2,4,5,7].

Placing any foreign object into a hive is challenging [6] and, from our experiences, we now know that introducing an array of hundreds of thermistors is possible. Furthermore, we have discovered that the way the sensors are provided is extremely important in determining if a colony will accept or reject the frames. Multiple layers of wax embedding the sensors may result in cells not perfectly aligning, or the wax being too thick for honeycomb construction. The second system used a single sheet of foundation wax, onto which the sensors were laid, and this was used normally for brood rearing and honeycomb construction, highlighting that minimal disruption to the foundation wax is optimum when designing such a sensor array.

Consequently, we can now collect highly valuable spatially resolved temperature data of a colony inside a brood box in a fully automated way, with affordable hardware.

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Conflicts of Interest: The authors declare no conflict of interest.

References

1. Braga, A.R.; Freitas, B.M.; Gomes, D.G.; Bezerra, A.D.; Cazier, J.A. Forecasting sudden drops in temperature in pre-overwintering honeybee colonies. *Biosyst. Eng.* **2021**, *209*, 315–321. https://doi.org/10.1016/j.biosystemseng.2021.07.009.
2. Moritz, R.; Southwick, E.E. *Bees as Superorganisms: An Evolutionary Reality*; Springer Science & Business Media: 2012. https://doi.org/10.1007/978-3-642-84666-3.
3. Kridi, D.S.; de Carvalho, C.G.N.; Gomes, D.G. Application of wireless sensor networks for beehive monitoring and in-hive thermal patterns detection. *Comput. Electron. Agric.* **2016**, *127*, 221–235. https://doi.org/10.1016/j.compag.2016.05.013.
4. Seeley, T.D.; Visscher P.K. Survival of honeybees in cold climates: The critical timing of colony growth and reproduction. *Ecol. Entomol.* **1985**, *10*, 81–88. https://doi.org/10.1111/j.1365-2311.1985.tb00537.x.
5. Stalidzans, E.; Berzonis, A. Temperature changes above the upper hive body reveal the annual development periods of honey bee colonies. *Comput. Electron. Agric.* **2013**, *90*, 1–6. https://doi.org/10.1016/j.compag.2012.10.003.
6. Meikle, W.G.; Holst, N. Application of continuous monitoring of honeybee colonies. *Apidologie* **2015**, *46*, 10–22. https://doi.org/10.1007/s13592-014-0298-x.
7. Eskov, E.K.; Toboev, V.A. Seasonal dynamics of thermal processes in aggregations of wintering honey bees (Apis mellifera, Hymenoptera, Apidae). *Entomol. Rev.* **2011**, *91*, 354–359. https://doi.org/10.1134/S0013873811030109.
8. Owens, C.D. *The Thermology of Wintering Honey Bee Colonies*; No. 1429; US Agricultural Research Services: 1971. https://doi.org/10.22004/ag.econ.171857.

9. Littelfuse 104JG1F Available online: https://www.littelfuse.com/products/temperature-sensors/leaded-thermistors/glass-encapsulated-thermistors/do-35-standard/104jg1f.aspx (accessed on 3 August 2022).
10. SparkFun Analog MUX CD74HC4067 Available online: https://www.sparkfun.com/products/9056 (accessed on 3 August 2022).
11. Teensy 3.5 Development Board Available online: https://www.pjrc.com/store/teensy35.html (accessed on 3 August 2022).
12. Raspberry Pi 3 B Available oniline: https://www.raspberrypi.com/products/raspberry-pi-3-model-b/ (accessed on 3 August 2022).
13. Stevenson, S. Observations of a Beehive Using 3D Thermal Monitoring. *Am. Bee J.* **2022**, *162*, 567–572.