IoT BEE HIVE MONITORING SYSTEM

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As apiaries become ever larger, beekeepers are unable to check every single hive and to evaluate its status. This always translates in some form of loss, economical or biological. This article describes a bee hive monitoring system, fitted with the latest technologies. Its main purpose is to ease the beekeeper's work. There are many such commercial systems, but this one combines latest technologies, a lot of sensors and advanced data visualization, at a reasonable price.

Keywords: sensor node, internet of things (IoT), load cell, hive monitor, EDLC.

1. Introduction

Since the beginning, beekeeping relies in the beekeeper's careful observation and experience. Every hive's status is evaluated by checking it regularly. As industrial apiaries grow larger, checking every hive is no longer efficient. The main purpose of the system described in this article is to ease beekeepers' work, by automatizing part of the observation work. When the colony's behavior changes, specific hive parameters change too, so the beekeeper can identify a possibly abnormal situation, or he can open the hive for a detailed observation.

There are several such systems, commercially available from professionals or homemade by amateurs, but they all have their weak points. Some use primary cells for power ([1]) and require regular replacement. Some do not offer enough sensors ([2][3]), and none of them process the hive's sound. Also, most of them are very expensive. The system described here is solar powered, acquires weight, temperature and humidity (in two measurement points), sound, tilt and offers an anti-theft solution. Detailed construction is revealed in [5] and [6]. It also comes with advanced display software and data storage at the user's system.

The system stands apart from other competitors by replacing the rechargeable batteries with a high reliability super-capacitor, with 20 years guaranteed lifetime and by extracting the buzzing audio spectrum (by FFT on the sound captured by a microphone), instead of its amplitude, making it available for further analysis. The main feature is a new population estimation technique, by counting bees using motion transducers instead of the classic image processing solution or LED-photodiode optical barriers.

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The paper begins with a brief description of the problems and illustrates why monitoring a hive is useful. Next section details the hive parameters and ways to monitor them, followed by a high-level schematic diagram and a brief description of the prototypes. Section 5 is dedicated to the weight measurement solution, emphasizing the calibration method. The next section illustrates a few tests and results. Conclusions are presented at the end of the paper.

2. Why monitor a bee hive?

We monitor the hive to ease beekeeper’s work. Meetings were established with local beekeepers, to determine exactly what they need. They explained in detail their observations and actions.

In the cold season, bees are keeping warm by gathering in a ball, so any kind of activity indicates that something is wrong. The beekeeper regularly listens the hives, with a medical stethoscope or directly, placing his ear on the box. During winter, hives are great shelters for mice. A colony stressed by rodents will be noisier and use a lot more honey. At the end of the winter, the queen starts laying eggs, so the temperature will rise by 10°C, reaching 35°C in the middle. This means higher honey consumption, and the hives with low reserves are in danger of starvation. An informed beekeeper can feed the endangered colonies.

When a colony runs out of food, bees become agitated (they buzz loudly) and will exit the hive in search of food, no matter the weather outside (frost, blizzard etc.).

Water vapors will condensate on the walls of an insufficiently ventilated hive, promoting honey fermentation and mold. In both cases, bacteria developed in the mold or in the diarrhea will kill the colony. If the beekeeper knows that a hive is very humid, he can improve its ventilation, saving his bees.

On the spring, bee star collecting nectar and pollen and the hives are rapidly developing. Beekeepers use a weigh scale to monitor the weight of an average hive, to identify the beginning and the end of a specific nectar foraging. Nectar type separation is useful to obtain a specific type of honey. In most cases, the scale is mechanical, and the beekeeper writes down its indication daily. The same scale is useful during winter, to evaluate food supplies (also manually checked).

In Romania, hives are reaching their peak in May-June. It is the moment for bees’ natural multiplication process, by swarming. For the beekeeper, natural swarming is not a good thing. The colony stops gathering nectar and the old queen leaves the hive with the flying workers, in search of a new place, to start a new hive. Several swarms can leave from a powerful colony, leaving it very weak. Fortunately, there are warning signs several days before: the weight won’t increase, the buzzing is stronger, with lower tone, internal temperature rises and the hive's entrance is very crowded. If the swarm already left, the colony from which it departed can be easily detected: the scale can indicate a weight drop of up to 3kg. The alternative is to powder the bees in the swarm with white flour, and to track them back to their origin hive (difficult to achieve in a large apiary).

During autumn, if there is no nectar in the area, the queen will stop laying eggs, and there won't be enough bees to pass the winter safely. Stimulation syrup is given in small quantities, to trick the bees to believe there is still nectar in the nature. If the beekeeper is negligent, he can trigger hive robbing: powerful colonies attack the weak ones and steal their honey. The scale is again useful, indicating a weight drop of the robbed hive.

Hives are always vulnerable to external attacks, coming from wild animals (where applicable), weather conditions (like strong wind) or man (theft). Any motion or dangerous tilt can be easily indicated by a cheap, accelerometer.

3. What to monitor in a bee hive?

Keeping in mind the situations described above, the beekeeper's observation work can be automated by monitoring the following parameters:

- Temperature: brood indication in the winter and swarming in summer;
- Humidity: indicates condensation, water infiltration and disease. Dew point can be calculated using the temperature readings.
- Weight: useful all year around.
- Sound: amplitude and pitch, useful in summer and winter.
- Tilt and movement: useful for theft detection.
- Hive entrance traffic: useful for detecting poisoned nectar (from pesticide treated crops).

It is useful to measure temperature and humidity in at least two places inside the hive: one in the core and the other somewhere in the box. Both parameters are measured with a single device, for easy installation and wiring. Required precision was set at ±1°C for temperature and ±2% for relative humidity.

The weigh scale must be designed to measure safely 80kg (the weight of a nest and a supper, with large frames). The beekeepers decided that a resolution of 0.1kg is enough.

When checking a hive by ear, the beekeeper is interested in the buzz amplitude and pitch. A microphone will be used to record the sound and to obtain the audio spectrum. This way, pitch changes can be tracked over time.

Tilt and motion can be easily detected by a cheap accelerometer. Specific thresholds can be programmed, to avoid false alarms.

Entrance traffic monitoring was attempted by many others, and their solutions involve image processing ([7][8][9]) or optical barriers ([10][11]). The first category involves expensive, complex and energy hungry equipment. The second one splits the entrance in narrow canals, the size of one bee, disturbing their activity, especially cleaning. It also comes with high counting errors and energy consumption. Radar [12] and RFID [13] technologies were also attempted, but only for short term research.

The solution selected by the system in this article steers away from the disadvantages of the previous systems by using optical motion transducers, used in optical computer mice. They are far more sensitive, more accurate and energy efficient. A wireless mouse runs for years on a single battery.

4. System description

The easiest way to understand the system's operation is by analyzing its block diagram (Fig. 1).

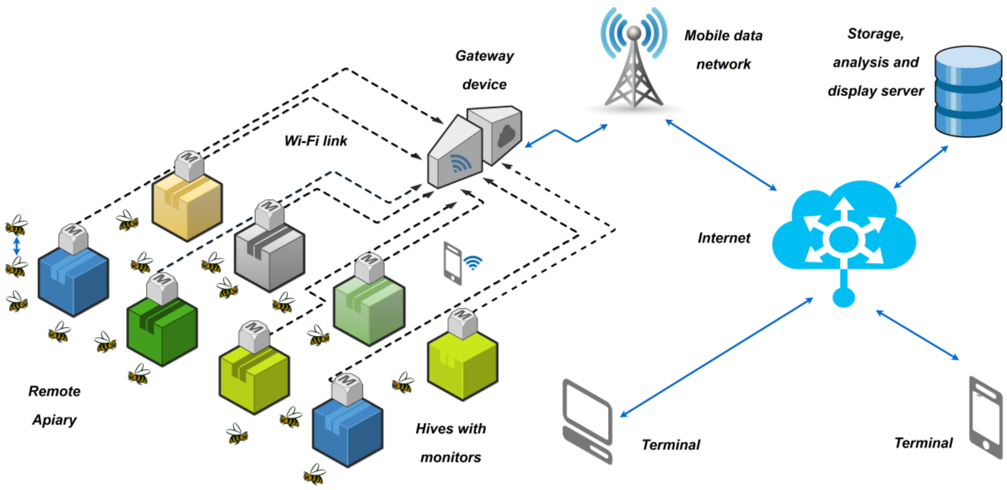

Fig. 1: Monitoring system block diagram.

The colonies under observation are fitted with hive monitors. They are powered by solar panels and send their information to a storage and analysis server, using a local WiFi network (a router).

If there is no WiFi available at the apiary, a gateway device is required, which emits its own WiFi network and connects the local network with the mobile data network. The gateway is also powered by solar energy and can accept up to 250 hive monitors.

The free version of Thingspeak was used for data storage and display, but, due to its limitations, a new platform has been implemented. The gateway and data server are still in development, under tests as weather stations, and were not installed in the author's apiary.

The hive monitor is powered by solar panels, and stores energy in a super-capacitor [4]. Sensors are attached using I2C bus, according to user's requirements, as the monitor has a modular architecture [5].

Temperature and humidity are monitored using combined sensors (Sensirion SHT21) in two measurement points. Sensors are built in such as to reach in the center of the nest, without modifying hive's structure or disturbing the beekeeper's work (fig. 2).

The sound sensor assembly (microphone and processing circuit) is built the same way (fig. 3). A MEMS microphone was selected, for its noise-immune digital output and its size.

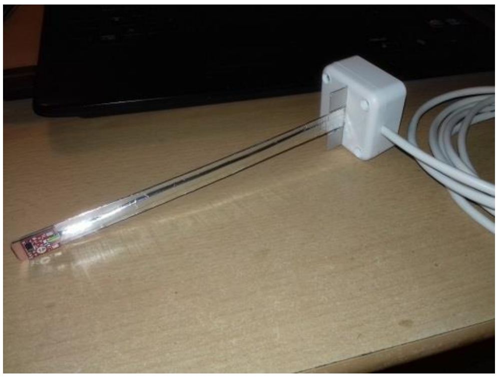

Fig. 2: Temperature and humidity sensor.

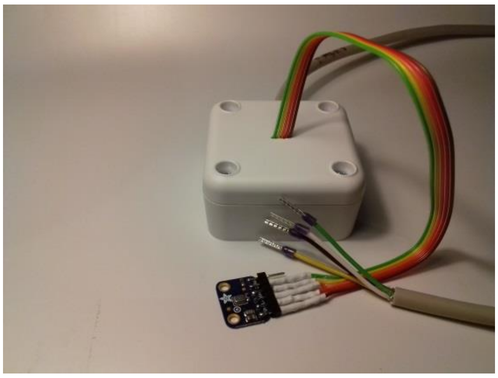

Fig. 3: Microphone and processing circuit.

The traffic monitoring prototype (still under development) contains six motion tracking sensors, managed by a micro-controller (fig. 4). Underneath, there are six canals, guiding the bees under the lenses, with the narrowed length of only 8mm.

The scale structure supports the entire system. It is built using four load cells (to eliminate tilt influence), connected to a dedicated converter.

The accelerometer is fitted in the external housing of the temperature sensor and it alerts the micro-controller if motion outside the predefined limits has been detected.

Most sensors are easy to interface, as they offer directly useful data (temperature, humidity, tilt). Measuring weight is not as simple and requires specific steps to be taken.

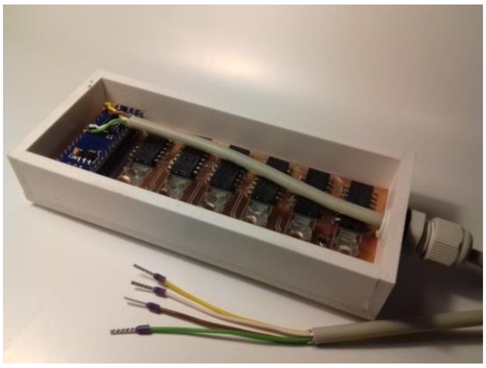
Fig. 4: Bee counter prototype.

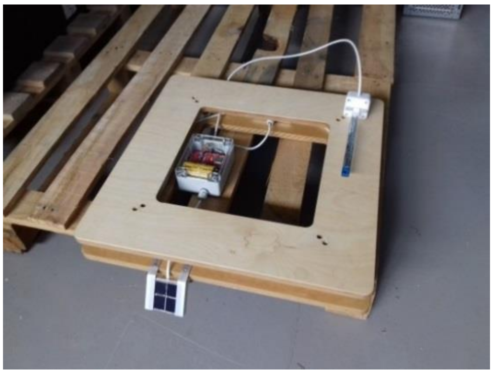
Fig. 5: Complete weigh scale.

5. Weight measurement

The prototype was designed for 80kg, with an absolute maximum of 120kg. A hive reaching this weight is not practical, as it cannot be moved anymore. The beekeeper extracts honey to prevent this. In the test conditions, a 20kg nest and a full-size supper (of max. 50kg) make a good fit for the 80kg scale.

The sensing assembly consists of four load cells, each one rated at 20kg, with a sensitivity of 2mV/V. The load cells are excited with 3.3V and the output signal is fed in a 24-bit ∑-Δ analog-to-digital converter (AD7780, by Analog Devices). It also features an internal amplifier, with the gain set to 128.

The load cells are located in the structure's corners and connected in parallel, to eliminate the influence of tilt and the center of mass shift.

The converter uses the well-filtered power rail voltage as reference (3.3V). With the gain set to 128, the maximum measurable voltage is ±25mV. A fully loaded load cell will output 6.6mV, so it comfortably fits in the converter's scale, allowing room for cell overload. It also leaves enough headroom for load cell zero offset, or tare (which can be up to 50% of its full-scale output voltage) and for load cell gain error (up to 20% of its full scale output). The converter has a noise of 44nVrms with the specified power and gain conditions [14]. The number of noise-free converter counts (N) is:

$$N = \frac{6.6mV}{6.6 \cdot 44nV} = 22727 \tag{1}$$

where the multiplication with 6.6 converts rms voltage to peak to peak voltage [14]. The resolution in grams is:

$$R = \frac{80kg}{22727} = 0.0035\ kg = 3.5g \tag{2}$$

The resolution is far lower than the required one, of 100g.

However, all load cells suffer from hysteresis, meaning they output different signals when adding and removing weights. Professional, high quality load cells specify the error due to hysteresis, but it is not the case of the ones used in the prototype (low cost ones). Table one contains converter data for 8-point calibration, when adding and removing weights, together with the difference in each point. Values are brought to zero by removing the offset, to make the data easier to understand.

Table 1

Prototype load cells hysteresis

Weight [kg]	Output when adding [N_{ADC}]	Output when removing [N_{ADC}]	Difference [N_{ADC}]
0	0	304	304
21.1	209827	270248	294
30.7	393501	393230	271
40.3	516798	516675	123
49.9	639564	639426	138
59.5	762989	762890	99
69.3	890386	890031	355
78.9	1014939	1014446	493

The difference might not look too much, but a single converter count means 3.5g (assuming only the converter noise). This means 1.7kg difference in the worst case and 1kg average over the entire range. Additionally, the difference is not constant for these load cells. The scale was loaded and unloaded three times, with similar results. One of the graphs is plotted in graph 6. The largest difference between the three graphs was 38 ADC steps, which theoretically translates to ~133g (3.5g/step*38). For the rest of the scale, the average difference was less than 20 ADC steps. This is not a problem, because only the daily variation of the weight (the delta) is important, not the absolute value.

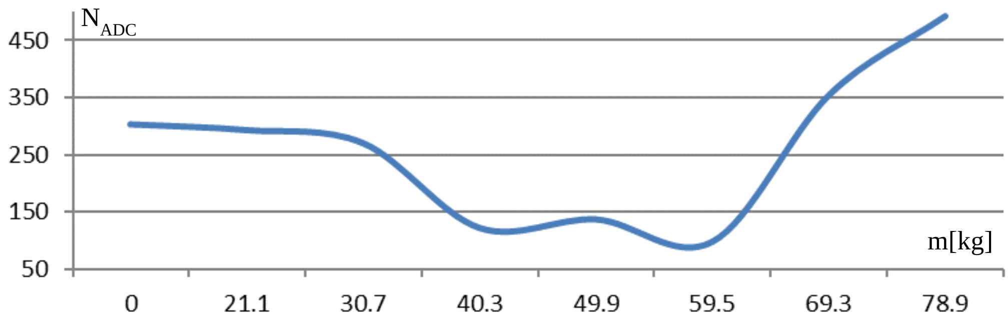

Fig. 6: Hysteresis amplitude: difference between adding and removing weight curves.

An equivalent curve was plotted, to reduce the hysteresis influence, by averaging the values of the adding-weight curve and the removing-weight curve. The result is plotted in graph 7. It is linear on the middle and top part of the scale. This is useful; of highest interest is the end of a nectar flow, when the hive is already very heavy.

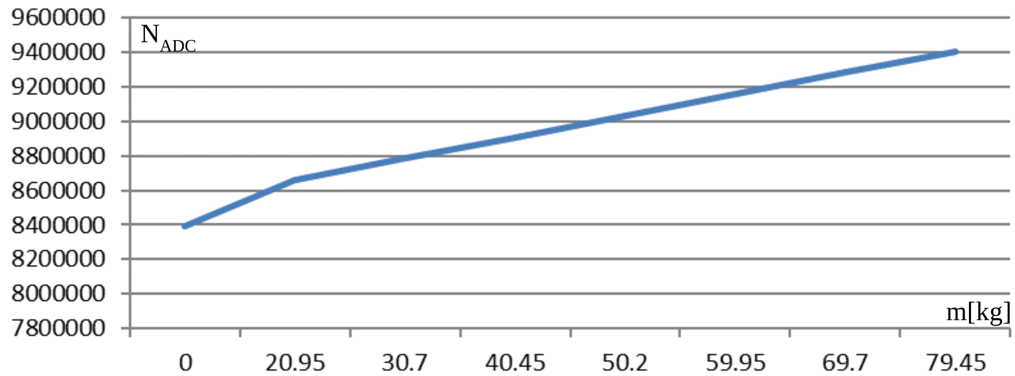

Fig. 7: Final calibration curve: converter counts (N_{ADC}) and mass (m).

Still, it is not linear on the full scale, so a two-point calibration introduces errors. Eight calibration points were selected (at zero and from ten to ten kg), with Lagrange interpolation, because it does not require equally spaced calibration points and it is easy implementation.

The Lagrange interpolation polynomial is a P(x) polynomial, of degree ≤*(n-1)*, passing through *n* points (x, f(x)), given by [15]:

$$P(x) = \sum_{j=1}^{n} P_j(x) \tag{3}$$

where:

$$P_j = y_j \prod_{\substack{k=1 \\ k\neq i}}^{n} \frac{x - x_k}{x_j - x_k} \tag{4}$$

This way, for a converter result located somewhere between the calibration point, weight is approximated on the curve obtained from the averaging of the adding-weight curve and the removing-weight curve.

The scale is built from 15mm thick aviation plywood, milled on a CNC machine and sealed with epoxy resin for moisture protection (fig. 8). The central opening is dedicated to anti-varroa open-bottom hives, allowing waste to fall to the ground.

The result is a scale capable to reputably measure the weight of a pencil (13g), even after placing and removing 21 kg. Calibration was made with concrete bricks, of 3.25kg each, 24 in total.

6. Results

First tests were conducted with fixed weights (bricks, flower pots etc.), at different temperatures, and only after proper operation confirmation it was put to good use. On July 13th, 2018, a system made of a scale and two temperature and humidity combined sensors was fitted to a hive in Baldana, Romania (fig. 8 and fig. 9).

Fig. 8: Hive fitted with a monitor.

Fig. 9: Temperature and humidity sensor.

Data was sent to the server using a 3G access point, placed in the apiary (the gateway was not ready at that moment). This article uses data collected until August 4th, 2019; a complete beekeeping year (starting in Romania around August 1st). However, it is not raw data that matters, but its meaning and the decisions made upon them. Fig. 10 shows the first tests: the weight of some flower pots, of ~3.2kg, watered in the evening, and, sometimes, in the morning. Weight drops as they dry out in the hot summer days, and it rises when they are watered. A rainy day stands out, as the pots are filled with water.

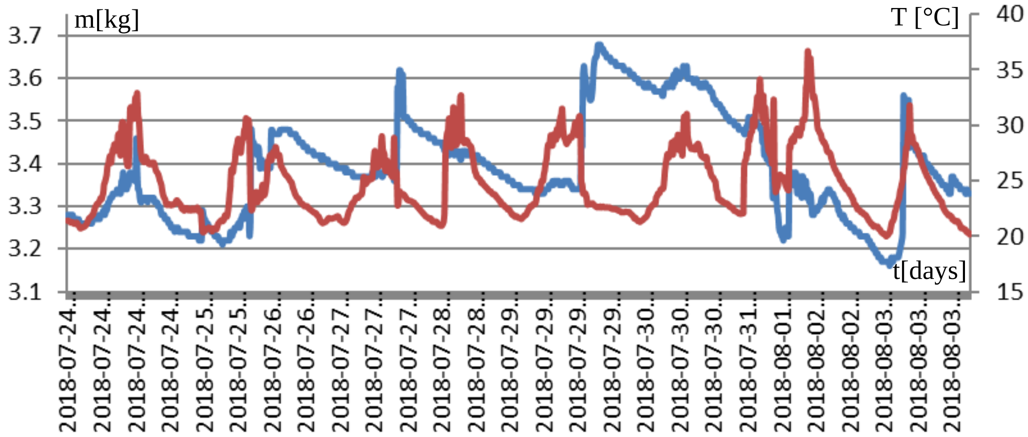

Fig. 10: Tests: flower pot weight (blue) and environment temperature (red).

Fig. 11 shows the hive weight during the month of August. The large steps are syrup feedings, 1kg-1.5kg at a time, to complete the winter reserves. The smaller variations are created by the bees, leaving in the morning and returning before evening. The descending trend comes from syrup drying in the combs and concentrating, as the bees remove the water from it. It is obvious that there is no nectar in the nature.

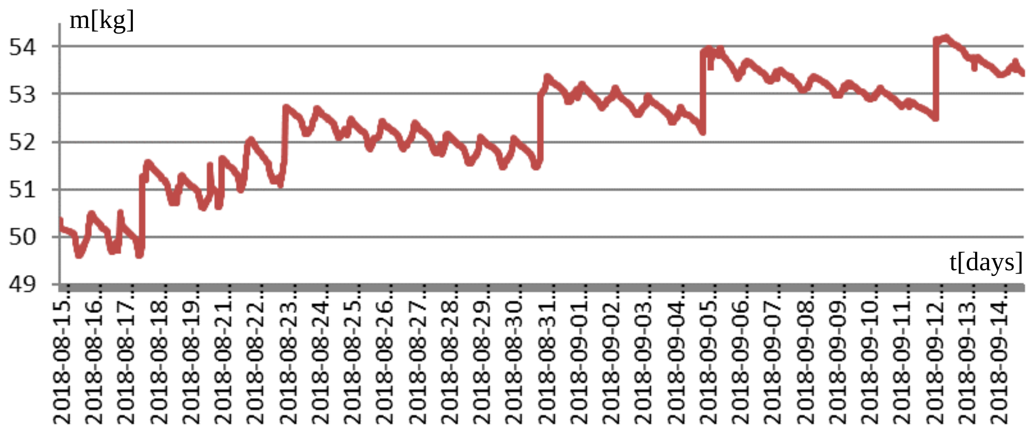

Fig. 11: Syrup feedings and bees leaving and returning to the hive.

In September, the nest temperature suddenly dropped, from an average of 30°C down to 20°C (fig. 12). The brood needs around 35°C during development, so this temperature drop indicated that the queen stopped laying eggs (most likely on September 20th). When all brood hatches, an anti-varroa treatment can be made, with greatest efficiency. Oscillations are created by the outside temperature, as the bees are not regulating the temperature anymore.

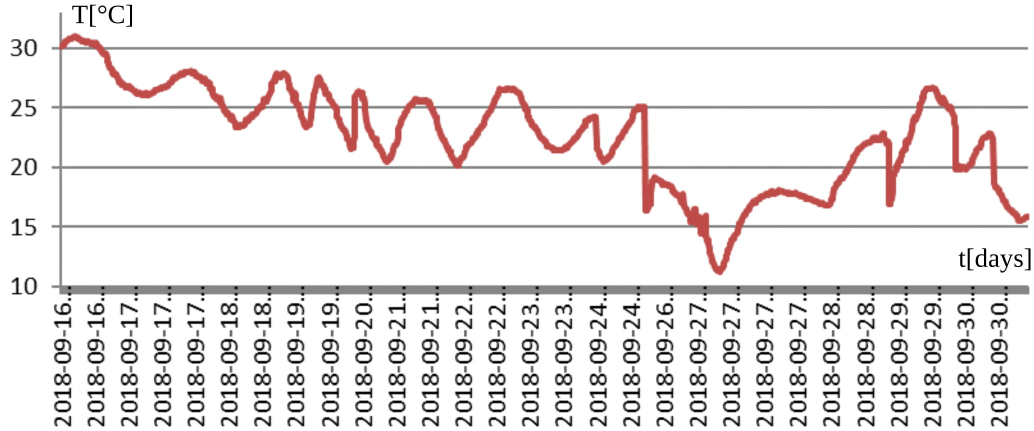

Fig. 12: Temperature dropping inside the hive, meaning the queen stopped laying eggs.

No abnormal situations occurred with the monitored hive: it hibernated normally (food reserves were tracked using the scale), no sign of disease or excessive moisture (sensors did not indicate high values), it did not swarm in the summer (no sudden weight drops), it has been rarely disturbed, to add the supper and for status checks, and the nectar foraging was not impressive.

Perhaps the most spectacular event caught on record was the cleaning flight, performed at the beginning of spring, during which the bees evacuated an impressive 2kg of excrements, accumulated in their bodies the whole winter. A large-scale cleaning flight in the spring indicates a successful end of the winter hibernation, and it is closely observed by the beekeepers.

7. Conclusions

An affordable, easy to use bee hive monitoring system was developed, relying on information gathered from beekeepers. The system is powered by solar energy, does not require maintenance, does not require structural changes of the hives and is has a modular architecture, with easily attachable sensors. Additionally, it is a perfect fit for the IoT technology, applying its principles in this antique activity.

There is still a lot of work to be done to finish the system, but it already outputs useful data, easy to understand by any beekeeper, experienced or beginner.

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