BeeSmart: a real-time remote monitoring and control system for beekeeping

Juan Navarro, Fabio Lima, Marín Porto, Leonardo Steinfeld
Instituto de Ingeniería Eléctrica, Facultad de Ingeniería, Universidad de la República
Pablo Cracco
Unidad de Apicultura, Facultad de Agronomía, Universidad de la República, Montevideo, Uruguay

***Abstract*—The development of agriculture has generally come with an increase in the use of agrochemicals and our region is no exception. In consequence, beekeeping production has been negatively affected by the death of bees and product contamination. Besides, the beehive's state of health is a good indicator of the quality of the environment in the area. However, beehives usually are located in remote sites that hamper frequent visits to asses beehive health. Remote monitoring of the production of honey and beehive health would be beneficial for the beekeeping community and also for environmental supervision.**

This work presents a prototype of a real-time monitoring and control system for apiaries as a first step to providing an integrated solution to beekeepers. The system consists of a device installed in each beehive to measure parameters of interest, such as internal temperature and weight, and transmit this information to a hub connected to the Internet. The internal temperature map is a proxy for the presence and activity of bees. The information collected is presented to beekeepers through a web application where they can access the data of each beehive and open or close its door. Preliminary results show that the proposed approach and system architecture are very promising. Future work includes building a more robust mechanical design, assessing other communication technologies, and a more affordable solution.

***Index Terms*—beekeeping, apiculture, wireless sensor network, environmental monitoring, internet of things**

I. Introduction

The increase of agrochemicals used in conventional crops has seriously affected the health of beehives, as well as the quality of honey. In addition, apiaries are usually in isolated or remote areas for the beekeeper, generating significant delays between needing to take action and becoming aware of it. A remote system that collects and process data from the beehive and sends them to the beekeeper will shorten these delays as decisions can be made remotely. This information will also be a bioindicator for environmental quality in the area.

Several works have addressed this problem. Becher et al. [1] developed a model to study the impact on the brood temperature and bee colony development, concluding that colony survival is dependent on the number of bees available for heating the brood. The work also shows that temperature within the brood remains constant and it varies linearly between the brood and the box sides. Meikle et al. [2] also report a correlation between the temperature and temperature variability of the colony and its overall health, including future brood production.

Zacepins et al. [3] use temperature measurements to remotely predict swarming. The study finds that during the warm-up before swarming, the colony's temperature will increase by 1.5ºC to 3.4ºC. In this case this warm-up could be detected by a single-point temperature measure, up to 20 minutes before the colony swarms.

Kviesis et al. [4] propose several architectures for remote beehive monitoring depending on the needs and resources of the beekeeper. One described approach is to install a device on each hive with wireless communication to a central unit with Internet connection.

Based on these approaches some solutions were developed and reported. Wakjira et al. [5] detail an use case for the SAMS project (Smart Apiculture Management Services) in Ethiopia. The work detail the construction, implementation, and possible business models for remote beehive monitoring in Africa and Asia. For data acquisition, they mounted a device on one of the frames inside the brood box. Cecchi, et al [6] also uses a wireless sensor network with devices inside each broom box and a central unit with Internet access. Each device in the network has a power consumption of around 4 W so the must be connected to the power grid.

These previous works shows that a nearly constant central temperature indicates the presence of brood, and measuring temperature in different points of the brood box could be used to estimate the brood size and position. On the other hand, daily weight variations are an indicator of the activity of the colony, meanwhile, long-term variations reflect on the honey production. In summary, it is generally agreed that internal temperature and hive weight are a good indicator of the health and state of the colony and that the later also is useful to plan honey collection.

The solution proposed in this work aims to implement the aforementioned approach with minimum disruption to hive and the beekeeper work, and at the same time at a low cost.

This paper is organised as follows. Section II describes the general concepts of a colony, beehive, and the beekeeper's work. Section III presents the architecture of the solution and its implementation. Section IV discuss the results. Finally, Section VI concludes this paper.

II. Beehives and apiaries

This work aims to develop a system able to be integrated into a Langstroth hive, as the one depicted in Fig. 1 where the

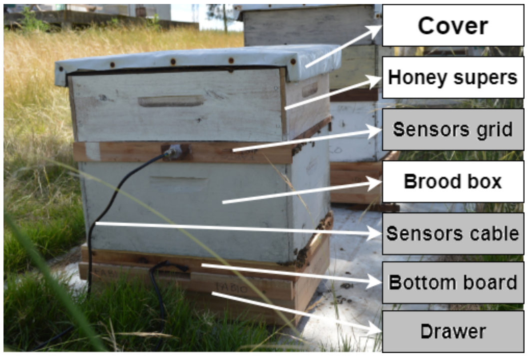

Fig. 1. Langstroth hive (with added parts to monitoring and control).

elements with white background are native of a Langstroth hive and the elements with grey background are added for this solution. The Langstroth hive is formed by a series of stacked boxes, with a top wooden cover and a bottom board with an entrance. The lower box, called the brood box, acts as a brood chamber (where the queen lays eggs that will later become larvae). The rest of the boxes, called honey supers, the bees produce and store honey. The brood box is separated from the rest of the supers by a queen excluder grid. Inside each box, there are frames placed in parallel. In these frames, the bees will build honeycombs, either to deposit the honey or the larvae.

The queen bee begins to lay eggs from the center of one of the central frames. Then she continues to lay eggs in an expanding circular shape, and the brood begins to grow into an ellipsoid volume within the brood box. The internal temperature is kept by the workers bees almost constant at 34-35ºC.

A typical apiary consist of between 20 and 30 beehives depending on the production scale. The separation between hives is around 2 meters and the average apiary radius is 20 meters. Beekeepers wear a protective suit while handling the hives, which limits their movements, and also they use smoke to calm the bees. Besides, it is important to disturb as little as possibles the bees.

III. Monitoring and control system

The proposed system is composed of one hive unit (HU) per beehive, a central or apiary unit (CU) per apiary, and a server. Fig. 2 shows the main components of the system.

The HU is responsible for measuring the internal temperature at different points and hive weight and transmit them to the CU, which is in charge of sending data to the server via a 3G Internet connection. The server makes recorded data available through a web application so that the beekeeper can monitor the hive in real-time.

A. Communication

Fig. 2 shows also the network topology and the different kind of links between the devices. The HUs installed on each hive and the CU form a 6LoWPAN network (IPv6 over Low power Wireless Personal Area Networks) in the sub-GHz ISM band. The 6LoWPAN is composed by the following protocol layers: IEEE 802.15.4 and TSCH (physical layer and medium access control sublayer), IPv6 and RPL (network layer), and CoAP (application layer over UDP transport layer). The CU serves as the TSCH and RPL root coordinator. This type of network allows the exchange of data wirelessly with very low power consumption, well below 1% of radio duty-cycle [7], which is ideal for the intended use, since this application requires relative low transfer rate.

The communication between the hub and the server uses TCP/IP over mobile network or WiFi, if available. The server has a public and fixed IP and the CU not, so the hub initiates the connection. At the application level, data exchange occurs using the MQTT protocol (Message Queuing Telemetry Transport, application protocol over TCP/IP with publish-subscribe architecture).

B. Hive unit

Each hive is equipped with a HU to monitor and control it. This unit is designed to minimize the disturbance of bees and the work of the beekeeper. The HU, depicted in Fig. 3, comprises of a system-on-chip (SoC) module with a micro-controller and a sub-GHz radio transceiver for processing and communication, a servo subsystem to control bee entrance (open and close a door), four strain gauges and an auxiliary electronic circuit to weigh the hive, a set of temperature sensors, and a power supply subsystem feeds from a battery.

All new items added to the Langstroth hive aim to make as little impact as possible on the bees and the routine work of the beekeeper. These elements are mounted in two different parts: lower and upper sections. One is placed below the bottom board (lower section), comprising the SoC module, the servo subsystem, and the weight and power subsystems. In addition, a grid of temperature sensors distributed in a wood frame is placed below the queen excluder (upper section), as showed in Fig. 1 and depicted in Fig. 4.

The system-on-chip (SoC) module and the weight auxiliary electronic circuit are placed inside a waterproof case. This case and the battery are placed inside a wooden drawer on the lower section. The load cells are fixed to the bottom board edges, close to its four corners. This is shown in green in the left section of Fig. 4 (horizontal cut). The bottom board, and the whole hive, is supported by the drawer, shown in pink in the right part of Fig. 4 (vertical plane cut). The objective of this drawer is to support the strain gauges, giving them a rigid and flat place for their correct operation and acts as protection for the waterproof case and the servo. The drawer has guides and dowels that limit the movement of the hive to ensure stability.

The wood frame with the nine temperature sensors distributed in three lines is shown in orange, in the left section of Fig. 4 (horizontal plane cut), and in the right section, located between the brood box and the queen excluder. All sensors are connected through a PCB that is embedded in the wood and sealed with Epoxy resin. The output of the PCB is connected to a lateral 1-wire connector for a three-pole rubber cable that connects to the SoC module.

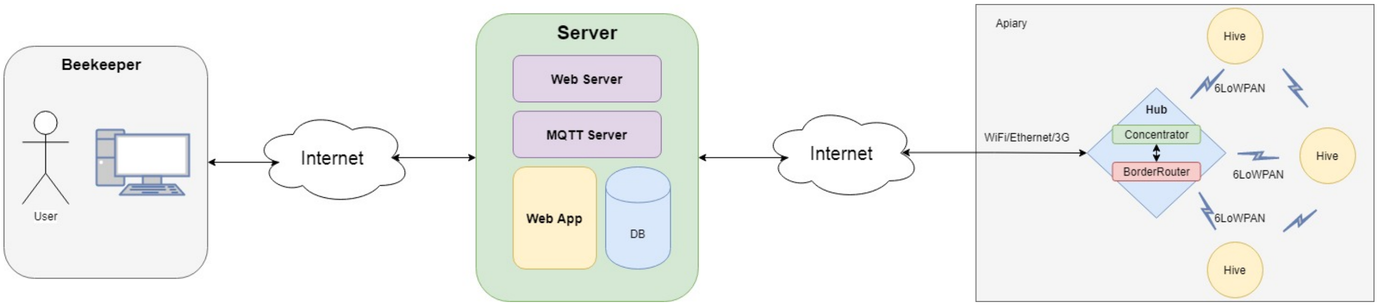

Fig. 2. Architecture of the system.

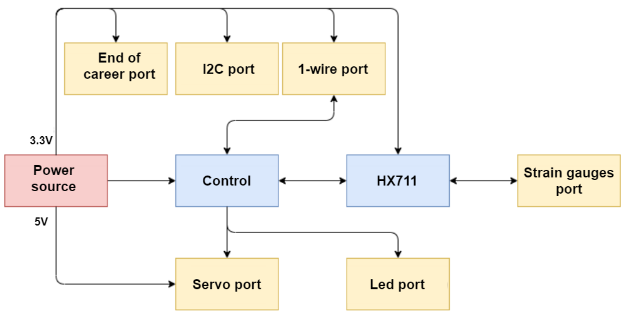

Fig. 3. Hive node construction.

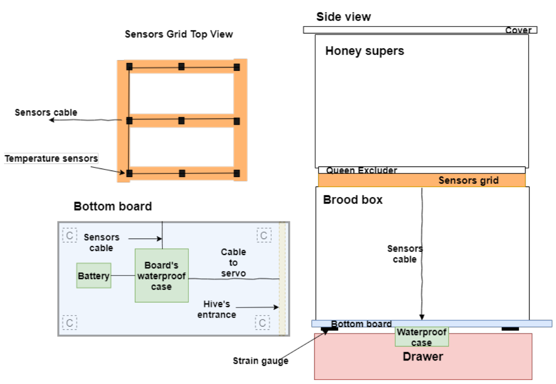

Fig. 4. Hive node construction.

The SoC module is a LAUNCHXL-CC1350 development kit from Texas Instruments with a CC1350 chip. The CC1350 contains a 32-bit ARM® Cortex®-M3 processor and a very low-power RF transceiver in both Sub-GHz protocols and 2.4 GHz. This development kit is chosen to take advantage of the ease of integration with the other components. A PCB is designed to be stacked on top of the launchpad, which includes auxiliary circuits and connectors to the sensors and actuators. The launchpad's built-in power-supply module based on the CC1350 chip was used to provide 3.3 V and 5V to other subsystems. The module has a built-in antenna featuring a compact size form factor.

For temperature measurements, nine well known and cheap DS18b20 temperature sensors are used. These sensors use the 1-wire protocol, work in a range between -55ºC and 125ºC, have an active energy consumption of 1 mA, and 1 μA on stand-by mode. The weight is measure with four strain gauges and a Hx711 amplifier which is specifically designed for this purpose. Regarding energy consumption, the weight measure sub system consumes 1.6 mA on active mode and less than 1 μA on standby.

The software of the HU is developed based on the Contik-NG[1] software platform, an operating system that includes the network protocol stack implementation described below. A custom firmware is developed to implement the application, including sensors drivers, data collecting subsystem, power management, functions related to the CoAP application server for the data exchange with the central unit, and some basic recovery mechanisms like verify the connection to IEEE 802.15.4 network, check if the sensors are sending data or auto re-boot if the device can not recovery the connection with the network or sensors. Data collected is sent to the hub, which in turn can also send commands to the HU, such as opening/closing the entrance, taking measures on demand, calibrating sensors, or rebooting.

The HUs are battery-powered, this was taken into account when choosing the sensors, and for developing the firmware, since it is needed for the CC1350 to enter LPM (*low power mode*) for as long as possible.

The HU power consumption was measured with the Otii Arc power supply and analyser, resulting in 500 μA on stand-by mode and 15 mA during the data exchange phase. It is expected an average power consumption below 1 mA, if the data are collected for a period of 5 minutes.

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C. Central unit

The CU is comprised of a single-board computer (SBC) and a border-router (BR) device or node.

The BR is the root of the wireless 6LoWPAN mesh network composed by the HUs (see fig 4 for more detail). This root receives the data sent by HUs. The BR connects to the SBC via a USB port (virtual COM connection). The BR forwards all messages received from HUs to the SBC, as well as forwarding messages from the SBC to any particular HU. The SBC has

[1] www.contiki-ng.com

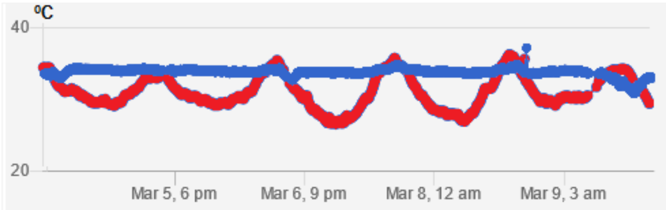

Fig. 5. Temperature inside the brood box, in center (blue) and next to one side (red).

connection to Internet via 3G, and forwards the data received by the BR from HUs. The SBC is also capable of receiving messages from the server, which can be used for take actions, or to be forwarded to the BR (and subsequently to an HU).

The SBC is implemented using a Raspberry PI 3 platform. It features a quad-core 64-bit ARM Cortex A53 running at 1.2 GHz, Bluetooth 4.1, WiFi, four USB ports and an Ethernet port. It is selected because, it is a powerful single-board computer at a very low cost (around 35 US dollars). Since, it runs a linux-based operating system, Ubuntu Core 16 for Raspberry PI 3, it supports Python, which enables to use practical libraries and run scripts.

For internet access, a 3G modem dongle is used connected to an USB port. During boot up, the SBC will automatically look for the modem and establish a connection. The SBC is also responsible of maintaining the internet connection and MQTT queue handle, recovery mechanisms, and log system. These processes are managed by a central software programmed in Python.

D. Server

The server implements the services and systems necessary to allow the visualisation and storage of the data of each hive (web server, database, message queue). A Ruby-on-Rails web application was developed for the project. This application manages the data and provides visualisation and an interface to send commands to each node. The application and the hub communicate with each other through an MQTT queue. Apache2 was used for the webserver, Postgresql for the databases, and Mosquitto for the MQTT server. All systems run on Debian based system.

IV. Results

Three HUs and one CU were installed in an apiary located in an experimental field. The system was tested for three months in which data was collected correctly. In that period, some failures were detected and automatically resolved by the system's recovery mechanisms. The HUs were powered by a 8000mAh battery and no recharge required.

Fig. 5 shows the temperature graph of two sensors inside a brood box in five days during the test in a real beehive, one in the center of the box (blue) and another next to one box side (red). The temperature corresponding to the sensor near one side of the box, fluctuate during the day following the outside temperature, while the other, corresponding to one central sensor, stay constant at approximately 35ºC. The temperature corresponding to the sensor near one side of the box fluctuates during the day, close to the value of the outside temperature (not shown), while the other temperature graph, corresponding to a central sensor, remains constant at approximately 35ºC. An almost constant temperature, regardless of the outside temperature, indicates that the brood is present in the area and the hive is maintaining its temperature.

V. Conclusions and Future Work

A system was design and manufactured capable of collecting data from hives on remote locations and sending them to a web server accessible to the beekeeper via the Internet in addition to controlling the beehive door through a servo motor. The beekeeper manages to obtain data from each hive in his apiary, allowing him to control the state of health and production of it. The designed system does not hinder the beekeeper's tasks and is adaptable to any Langstroth hive. The system automatically sets a network of HUs, it can add any new HU simply by placing it within the network area. Once a HU boots, it begins collecting data without human intervention. The collected data is sent to the CU, which in turn sends it to the server. Secondly the beekeeper could block the exit of bees if required, for example if someone are fumigating nearby.

One of the most relevant aspects to improve is the design and modifications on the hive since their imperfections may be they can considerably shortened the useful life of the nodes.

Another improvement would be to design a dedicated board for this project and stop using the Launchpad TI-CC1350. This change would reduce costs and optimise consumption, which would also facilitate mass production. Other improvements could be adding more sensors, trying other transmission protocols (such as NB-IoT, LoRA, or BLE), and building a solar-energy powering system for the hub and nodes.

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