IOHIVE: Architecture and Infrastructure of an IOT System for Beehive Monitoring and an Interactive Journaling Wearable Device for Beekeepers

Charalambos Alifieris[1], Theodora Chamaidi[1[0000-0003-4353-278X]], Katerina Malisova[1[0000-0002-6815-0748]], Dimitrios Mamalis[2], Evangelos Nomikos[1[0000-0002-4711-8677]], Chrysostomos Rigakis[1], Evangelos Vlachogiannis[1] and Modestos Stavrakis[1[0000-0002-0694-6038]]

[1] University of the Aegean, Department of Product and Systems Design Engineering, Syros 84100, Greece
{babis@, theodora.chamaidi@, katemalisova@, v.nomikos@ , chr.rigakis@, evlach@, modestos@}aegean.gr
[2] Kudzu P.C., Syros 84100, Greece
dimitris.mamalis@kudzu.gr

Abstract. IOHIVE is a project that focuses on the development of a smart apiculture system that incorporates sensors to monitor the weight, temperature, humidity, pressure, and sound of beehives. Additionally, the project involves the development of a wearable device that beekeepers use to interactively keep notes (journaling) of their empirical observations during beehive inspections at the apiary. This paper presents the architecture of the IOHIVE system/service, which consists of hardware infrastructures, including sensors, microcontrollers, network infrastructure (LoRA, Wifi, GSM/4G), as well as the wearable and its hardware and software. The software infrastructure includes the IOHIVE Service API, database, and the IOHIVE web application and its frontend and backend. The paper also describes the IOHIVE approach to smart beehive monitoring and journaling including the scenarios of the beehive inspection workflow, which includes the minimal and standard inspection scenarios. The IOHIVE system provides bee stakeholders, beekeepers and/or researchers (both mentioned from now on as beekeepers) with real-time monitoring of the beehives, enabling them to make informed decisions in time, resulting in improved bee health and productivity. The wearable device, coupled with the IOHIVE web application, provides a digital beekeepers' journal that assists people in recording their observations in real-time on the field, enabling them to maintain accurate records of their beehives and bee colonies, and potentially identify trends over time.

Keywords: Beehive, Monitoring, Journaling, Smart Apiculture, IoT, Wearable.

1 Introduction

The design of technologies for sustainable apiculture can help people, in many ways, including monitoring and management of bee colonies, pest and disease detection and control, as well as improving the efficiency of honey production. In the past few years, the use of smart technologies in apiculture has been steadily increasing, while the introduction of the Internet of Things further boosted the development of various systems and applications in the field. Today, there are numerous examples of successful implementations that combine such technologies for remote beehive monitoring with automation and data analytics. Moreover, several systems and applications have also been developed to assist users during the beehive inspections and more specifically with beehive journaling. These can be categorized as mobile applications, web-based platforms and IoT hybrid monitoring systems. The IOHIVE project deals with the development of an integrated platform that combines a similar functionality with the aforementioned implementations in terms of monitoring, but also adds an additional layer of interaction regarding beehive journaling in real-time when performing inspections in the field/apiary.

In summary, the general objectives of the IOHIVE project are to design and develop technological infrastructures and services for: a) remote hive monitoring of beekeeping data, b) the growth of bee collonies in accordance with local climatic conditions, honey yield, and other hive-derived products, c) the support of beekeeping practices and management techniques targeting the proliferation and development of bee populations, d) the endorsement and exploitation of all products stemming from the practices of beekeeping. The project intends to collect, process, and display both quantitative and qualitative data to enhance operational efficiency and elevate the standard of the products [6]. This manuscript predominantly concentrates on the evaluation of the general structure and infrastructure fabricated to meet the project's requirements. Accordingly, the paper is structured in the following sections. The introduction describes an overview of the current status in smart beekeeping, precision apiculture and IoT, it discusses the benefits and challenges of using these related technologies. In the second section, beehive monitoring and journaling are discussed, outlining the key factors that should be monitored and recorded for optimal beehive management. In the third section, we describe the IOHIVE approach to smart beehive monitoring and journaling, including the hardware and software components, data collection and analysis methods, and user interface and interactions. Finally, the fourth section presents a short critical analysis of the advantages and limitations of the IOHIVE approach and outlines future directions for research and development.

1.1 The value of technology assisted apiculture

Smart beekeeping, precision apiculture, and the Internet of Things (IoT) along with other technologies and beekeeping systems have revolutionised the way bee stakeholders, including beekeepers, bee product producers and bee researchers, manage their hives. In recent years, advancements in sensor technology, data analytics, and wireless communication have enabled the aforementioned bee stakeholders to monitor their hives in near real-time, collect and analyze data, and make informed decisions based on the insights gained. On the one hand, smart beekeeping can help beekeepers increase hive productivity, reduce hive losses, and optimize resource use.

In a broader sense, smart beekeeping involves utilizing a range of technologies to achieve its objectives in supporting the beekeeping process. By leveraging sensors, cameras, robotics, drones, wearables, mobiles and other advanced technologies, smart beekeeping aims to monitor the health of the beehive and gather data on important factors ranging from environmental conditions such as temperature, humidity to bee or beekeeper activity and physiology. This data can then be further utilised to inform critical decisions about the relationship of people with the bee colonies, develop strategies for beekeeping and thus influence the actual practices of beehive observation, inspection and management. In a similar fashion, Precision Apiculture aims to help bee stakeholders identify and address specific issues related to bee management based on precise and data-driven strategies [1–3]. It involves collecting and analyzing data at a more granular level with numerous techniques and goals. It incorporates a number of different technologies ranging from geographical information systems (GIS), satellite imagery analysis and sensors to robotics and other advanced digital tools, to afford different applications for sustainable beekeeping [2, 4, 5]. These include: a) **site selection** to ensure that bees have access to sufficient pollen and nectar resources while minimizing competition with other colonies, b) **hive management** to create hive-specific management plans (e.g. for feeding, pest control, queen replacement etc), c) **pollination services** to optimize the pollination for specific crops, d) disease and pest management by monitoring the health of individual colonies and detect signs of disease or pest infestations early on and thus provide guidelines for efficient prevention strategies, e) **breeding programs** to improve bee breeding by identifying and selecting desirable traits, such as disease resistance or high productivity, based on the analysis of colony data and genetic information, f) **resource management** to optimise resource usage, such as feed, treatments, and equipment, based on the specific needs of each colony or location, and g) **environmental monitoring** to develop conservation strategies, such as habitat restoration or the creation of pollinator-friendly landscapes. Precision apiculture aims to maximize productivity, minimize resource use, and promote sustainable beekeeping practices by using technology and data to optimize hive management decisions at the micro-level. In summary, smart beekeeping can be considered a subset of precision apiculture. While both concepts involve using technology and data-driven techniques to improve beekeeping, precision apiculture takes a more comprehensive approach, emphasizing precise, customised management strategies for individual colonies and locations [6].

Moreover, advancements in computing and the Internet of Things (IoT) are playing an increasingly important role in supporting technology-assisted beekeeping [7–9]. IoT technologies mainly focus on interconnecting physical devices that are embedded with sensors, software and networking capabilities. The goal is to enable these devices to collect and exchange data with each other and the central systems they are connected to. In the context of beekeeping, IoT technology can be used to remotely monitor apiaries and beehives, automate tasks such as hive monitoring, data collection, and reporting, and reduce the need for frequent on-site visits by beekeepers. By using IoT-based monitoring systems, beekeepers can collect real-time data on factors such as temperature, humidity, and sound levels in their hives, and remotely assess the health of their colonies. This helps to minimize the amount of stress placed on the bees and can reduce the number of interventions required to manage the hives, improving colony health and productivity [10, 11].

On the other hand, there are challenges associated with using these technologies, such as the high cost of implementation, the need for technical expertise, and the potential for data overload [9]. Furthermore, concerns have been raised about the privacy and security of data collected through IoT devices, as well as the potential for these devices to interfere with bee behavior [7, 12]. Despite these challenges, the benefits of using smart technologies and IoT in beekeeping are clear, and these technologies have the potential to revolutionize the industry in the coming years. As such, it is important for beekeepers and researchers to continue exploring and developing these technologies, while also addressing the challenges and concerns associated with their use.

2 Beehive Monitoring and Journaling

Beekeeping is an agriculture-related practice that requires significant labor and attention in order to maintain the health and productivity of bee colonies. [13]. In their everyday practice, beekeepers routinely inspect the frames of each beehive almost daily, varying frequency based on the season and objectives. Through diligent journaling of observations and practices during field visits, beekeepers can draw insightful conclusions regarding the status of the beehive and forecast its future health. In addition, such journaling practices are also an effective means to validate the efficacy of beekeeping protocols, by tracking the progress and outcomes of the monitored practices. [13, 14]. Beekeeping inspections are often complex and journaling at the same time can become a challenging task as the beekeeper must deal with various tools and processes. Beekeepers often rely on empirical methods and tools, such as paper journals, to record notes on their observations during or after the inspection. These notes may include the use of symbols, numbers, or other shorthand to record their observations. However, the process of journaling during beehive inspections can be distracting and disrupt the beekeeper's focus.

The subsequent two paragraphs will be focused on presenting technologies and research that are associated with the practice of journaling and monitoring beehives.

2.1 Technologies used for Beehive Journaling and Monitoring.

A broad array of systems, services, and applications have been developed for note-taking or journaling during beehive inspections, along with monitoring conducted via sensors [2]. This includes both systems and services rooted in academic research and those available commercially, along with mobile applications accessible in most mobile marketplaces. Noteworthy open-source systems explicitly addressing the need for journaling encompass the Beep App, an online web service, accompanied by the Beep Scale [15], and OSBeehives application, supported by the BuzzBox beehive monitoring system [16]. Both services provide diary functionality to beekeepers and researchers, enabling them to take notes on the current status, treatments, and any changes made during inspections, among other factors, for each hive. Additionally, monitoring conducted via sensors is stored in databases and presented to users via various visualisation techniques, such as graphs, charts, and widgets. Both systems classify information according to the inspection checklists prevalently utilised within the beekeeping community [17]. As both systems are currently under substantial development, their graphical user interfaces and core functionalities are undergoing continuous updates, enabling users to seamlessly navigate via both their mobile and desktop devices.

Manual journaling by beekeepers is often complemented by automated systems that monitor a variety of data pertinent to an apiary, including beehive status and the microclimate of the surrounding area. The monitored data is captured and scrutinised by an array of systems and techniques, such as audio/acoustic or sound analysis [18, 19], motion/track analysis [20, 21], population estimation and variability [22, 23], behaviour analysis [24], vibration [25], image analysis, and computer vision for detecting diseases and parasites [26], energy consumption [27], and environmental data [28]. Several systems have also been developed to monitor combinations of the aforementioned data based on multi-sensor arrays, which fall under the domain of Internet of Things (IoT). Such systems typically monitor temperature, humidity, weight, audio, video, vibrations, among other factors. Some recent examples include BeePi [29], Beemon [30], an IoT concept for precision beekeeping [31], and an IoT project of a low-power beekeeping safety and conditions monitoring system [32].

2.2 Inspection and Journaling Workflow

Following the user research phase, the design team developed two standard inspection scenarios that run parallel to the monitoring of sensor data from beehive sensors and local weather stations. These scenarios are referred to as the ‘Minimal Inspection Scenario’ and the ‘Standard Inspection Scenario’. Detailed information about these scenarios is presented in another paper that has been submitted to another journal and is currently under review. Therefore, we will provide a brief summary of these scenarios here.

The Minimal Inspection Scenario.

The "Minimal Inspection Scenario" primarily centres on the steps that a beekeeper follows to assess the current status of a beehive by solely observing it without any interventions or beehive management. This scenario assumes that the beekeeper only observes the beehive status in the following pattern, consisting of two inspections named "Inspection 1" and "Inspection 2", (e.g., two weeks). It is important to note that the actual time duration may differ from the specified interval and has been presented for scenario representation purposes only.

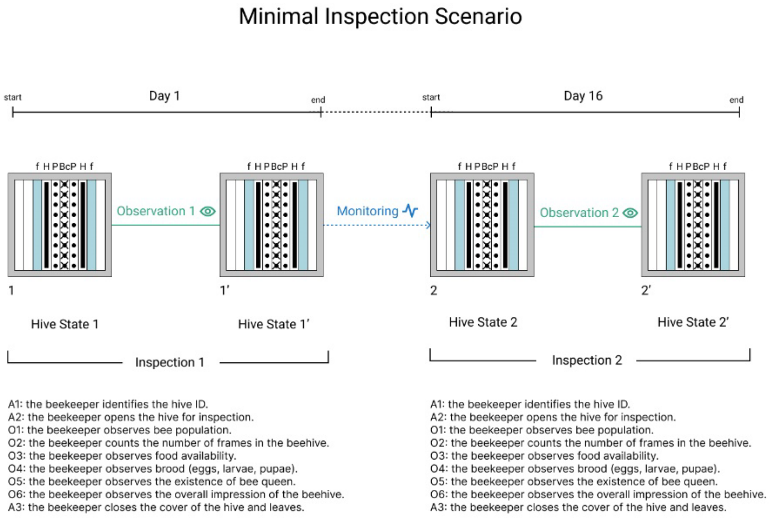


Fig. 1. Diagram representing the 'Minimal Inspection Scenario'

During "Inspection 1," which takes place on Day 1, the beekeeper performs the following tasks and observations in two hive states: "Hive State 1," which describes the beehive's condition before the beekeeper opens it, and "Hive State 1'," which describes the beehive's status after the beekeeper's inspection. In this scenario, the beekeeper only observes the condition of the beehive without any interventions, and therefore, "Hive State 1" and "Hive State 1'" are not heavily influenced by any beekeeping protocols. However, the state of the beehive is considered different primarily because even this mild intervention alters the status of the colony, as observed by the monitored data, such as changes in temperature and sound frequency. During "Inspection 1," the beekeeper performs the following observations and actions:

A1: the beekeeper identifies the beehive ID.
A2: the beekeeper opens the beehive for inspection.
O1: the beekeeper observes bee populations.
O2: the beekeeper counts the number of frames in the beehive.
O3: the beekeeper observes food availability.
O4: the beekeeper observes brood (eggs, larvae, pupae).
O5: the beekeeper observes the existence of bee queen.
O6: the beekeeper observes the overall impression of the beehive.
A3: the beekeeper closes the cover of the beehive and leaves.

During "Inspection 2," which takes place on the following apiary visit (Day 16 on this example), the beekeeper follows a similar approach, but the actual status of the beehive is altered due to the following reasons: a) the actual evolution that takes place

because of the actions performed by the colony, b) environmental conditions, and c) human interventions (even by observing).
The Standard Inspection Scenario that includes both user observations and interventions is more complicated as it involves significant alterations to the beehive's status by the human following a specific beekeeping protocol. This scenario is beyond the scope of this paper and is analysed in a separate publication.

3 The IOHIVE Approach to Smart Beehive Monitoring and Journaling

In this project we have developed the IOHIVE approach which utilizes a combination of digital technologies and human-beehive interactions to provide a comprehensive understanding of the current conditions within an apiary, including the state of individual beehives. Specifically, in-beehive sensors, weather stations, and wearable devices are employed to monitor the health, activity, and productivity of the hives. The following figure provides a high-level overview of the IOHIVE architecture.

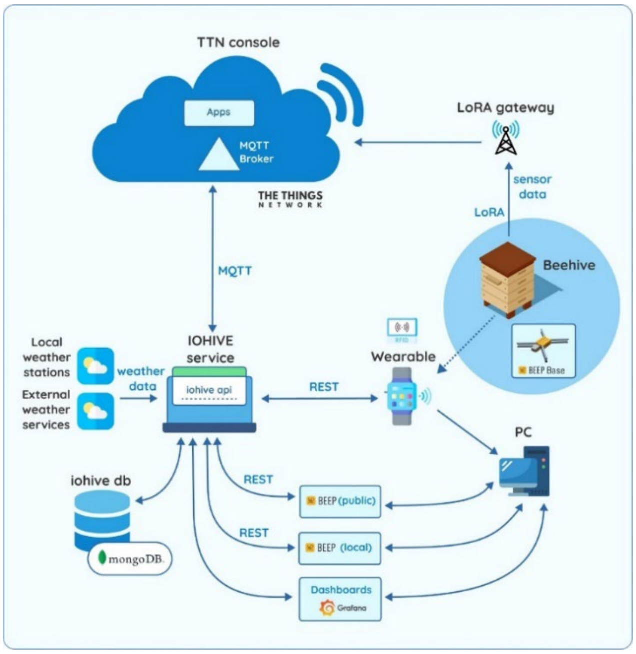


Fig. 2. IOHIVE System and Service Architecture

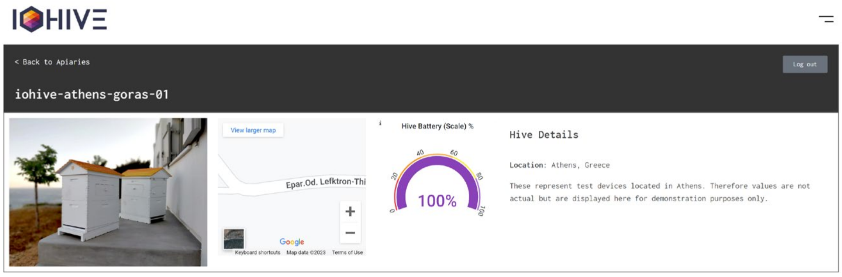
In this section, we will describe the different components used in the IOHIVE architecture and the related infrastructures that have been developed to fulfill the system/service's purposes. These components include the IOHIVE Architecture, LoRa/LoRaWAN implementation, LoRa Nodes and Gateways, Sensors, Weather Stations, and Wearables.

3.1 The IOHIVE Architecture

The IOHIVE architecture is centered around the IOHIVE Service, which is responsible for orchestrating the various data flows as described in the following sections. The IOHive Service acts as a bridge between the different devices involved, managing the different protocols and data streams coming from the users. These devices include monitoring devices, such as sensors, gateways, and weather stations, as well as wearable devices used in the field to perform inspections, and desktop clients where end-users can store and analyze data.

From a technical standpoint, the IOHIVE Service is a scalable application developed using NodeJS/NestJS, which subscribes to a TTN MQTT broker [33] for receiving data from the connected devices. Additionally, the service offers REST endpoints for receiving and serving data to users. The IOHIVE Service seamlessly integrates with both the public BEEP application [15] and a fork installation of the actual IOHIVE application [34], which extends BEEP's functionality to meet the project's requirements. The main service stores all data from the related services offered by the various projects' components in a MongoDB cluster, which provides timeseries collections and the powerful aggregation framework.

In practical applications taking place in the field (e.g. apiary), LoRa nodes are employed for the purpose of data aggregation from beehives. These nodes establish a connection with the closest LoRa gateway, which subsequently forwards the data to the public TTN network. The payload, accompanied by a unique device ID and timestamp, is then transmitted to the IOHIVE Service using suitable payload decoders and webhooks. Moreover, certain devices are equipped with 3G/4G connectivity and have the capability to communicate using SMS technology via an SMS gateway, a solution designed to surmount challenges posed by areas lacking in LoRa coverage. The IOHIVE Service bears the responsibility for preprocessing the data, encompassing tasks such as validation and formatting, before committing it to the database. In addition, the service furnishes endpoints for data extraction and aggregation that are intended for use by the IOHIVE App. Grafana functions as the principal framework for generating charts and integrating them within the IOHIVE App. Through the strategic utilisation of both the MongoDB aggregation framework and Grafana, a framework for data visualization is portrayed, facilitating the derivation of valuable insights.



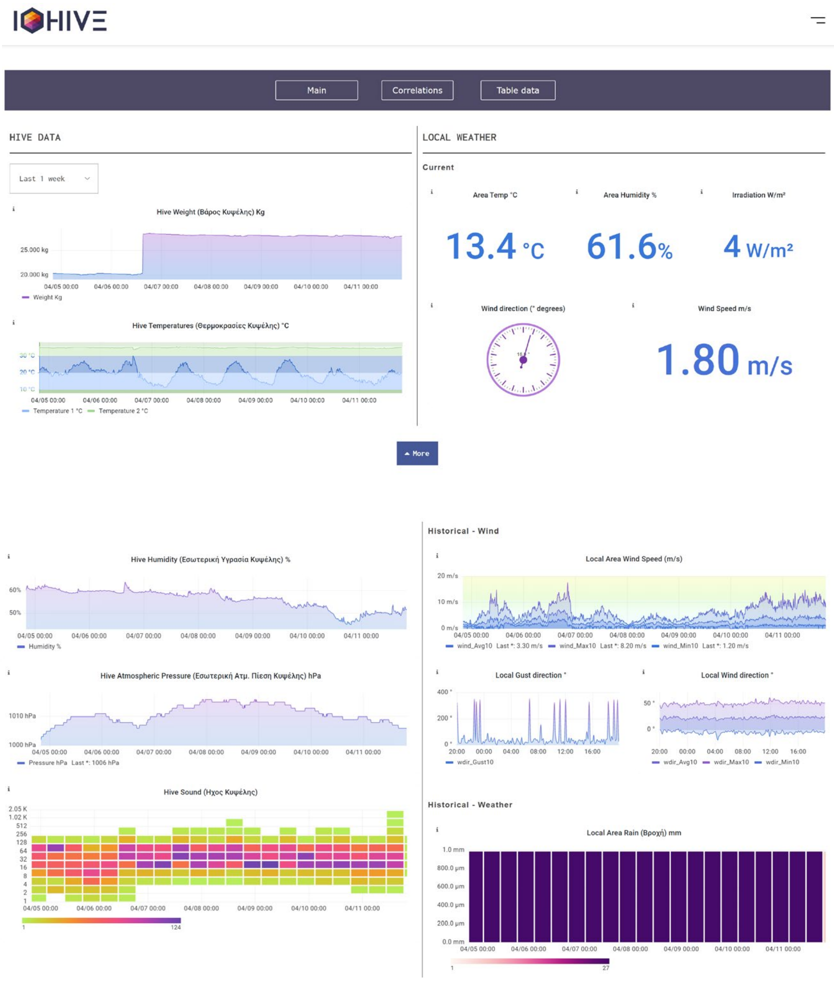


Fig. 3. The IOHIVE early v2 prototype interface includes visualisations and charts that display various information related to beehive monitoring and local weather data.

The data gathered from continuous monitoring of the beehive and its surrounding environment can be cross-referenced with the data gathered during inspections. By extracting and analyzing data windows for each inspection cycle, the user can gain insights into the issues encountered during the previous inspection period and plan appropriate corrective actions. The attainment of this can be facilitated through the deployment of suitable visualisation techniques.

However, the availability of communication channels such as LoRa, 3G, or SMS, poses several restrictions related to data rate, payload size, and cost. For instance, LoRaWAN has a raw maximum data rate of 27 kbps, which has been studied extensively to understand its limitations [35]. The Things Network website [33] provides a useful summary of these limitations and best practices. Therefore, it is essential to take these limitations into account when designing both the architecture and the interaction techniques used in the IOHIVE system.

The current state of the IOHIVE architecture integrates both the BEEP app (application/platform) and the BEEP base (hardware scale). The IOHIVE Service facilitates the transmission of data from various sensors to the BEEP app. Additionally, wearable devices transmit inspection data directly to the IOHIVE API service, which then forwards the data to the BEEP app.

To address the outcomes of the user research that took place in a previous stage and presented in this publication [11], a series of inspection checklists were developed. A data transformation layer, integrated into the IOHIVE Service, is responsible for converting data from multiple sources into formats that are optimally compatible with different interfaces. This capability enables the development of dynamic and configurable checklists that that meet the specific requirements of end-users.

Despite the BEEP framework's provision of configurable checklists, our inspection requirements necessitated an extension of this capability. As a result, we have extended IOHIVE app to accommodate our specific needs for inspection, which can be encapsulated in the following abstract, BEEP-agnostic Data Transfer Model (DTO).

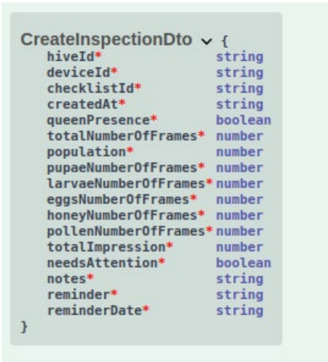


Fig. 4. IOHIVE’s inspection data model.

We have created a mapping of this model to the aforementioned checklist to integrate it with BEEP and leverage BEEP's functionality and accumulated experience in the field.

Hive Monitoring and Workflow

The architecture outlined above and its integration with BEEP and IOHIVE apps enables efficient management of apiaries and hives, connected monitoring devices, and alert mechanisms, such as low battery notifications, right out of the box.

The following sequence diagram illustrates the monitoring process. Sensor data, such as that from weather stations, scales, and temperature sensors, is predominantly transmitted via Lora. Lora Gateways then transmit the data to TTN, and our service receives the messages, stores, transforms, and forwards them to BEEP installations, in combination with interactive Grafana charts.

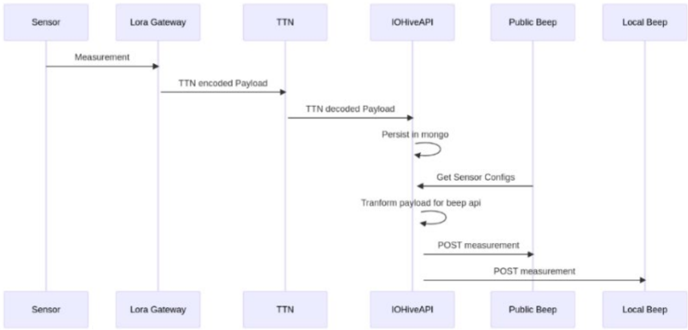


Fig. 5. IOHIVE Sequence diagram

Inspection workflow.

The sequence diagram below presents the inspection flow. A user wearing such a device initially scans the QR on every hive in order to identify the inspection target. The device fetches either from local storage or from IOHIVE Service at the last inspection. The user adjusts the values (see model above) based on her observations and data is being either persisted locally or directly transmitted through IP/REST to our service. The service persists, transforms and publish inspections to beep installations.

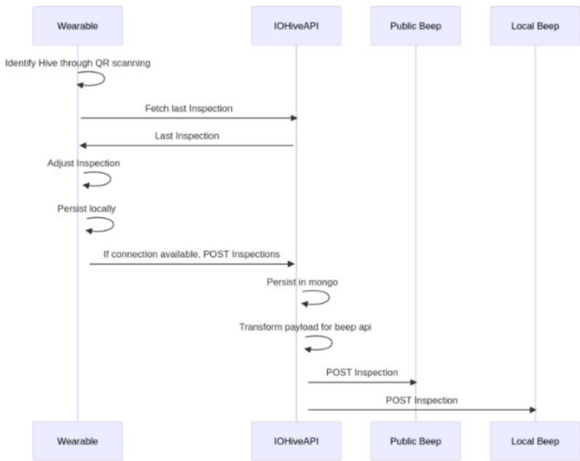


Fig. 6. Inspection Workflow Diagram

IOHIVE Service API.

The IOHIVE Service provides three distinct APIs:

- IOHIVE Sensor (Data) API - responsible for the integration of sensor data
- IOHIVE Weather (Data) API - responsible for the integration of weather data

- IOHIVE Inspection (Data) API - responsible for the integration of inspection data

Fig. 7. IOHIVE Service API

3.2 LoRa/LoRaWAN implementation

Drawing on the design requirements and research gathered during the initial stages of implementation, the focus of this project is to utilise IoT technologies that provide long-range wireless communication at a low bitrate between connected objects, including sensors that operate on a battery. The IOHIVE project employs LoRa, a long-range, low-power wireless technology, to remotely monitor beehives. By operating in the unlicensed radio spectrum and offering low data rates, it enables the deployment of cost-effective, energy-efficient IoT devices for beekeeping. LoRaWAN, a wide area network protocol, standardizes the communication and system architecture for the network, including end nodes, concentrators, network servers, and application servers. Given its far-reaching transmission capabilities, LoRa is an optimal solution for connecting beehive sensors and actuators across varied landscapes, thereby supporting the development of the IOHIVE project. LoRaWAN networks, employed in the IOHIVE project, use a bidirectional ALOHA-based protocol to facilitate uplink and downlink communication. In uplink, end devices send messages without targeting specific concentrators, which forward them to the Network Server, and ultimately, the Application Server processes the data. Downlink follows the reverse order, with the Application Server sending encoded messages back to end nodes. LoRaWAN's combination of modulation technology, system architecture, and unlicensed ISM band operation makes it an ideal choice for large-scale IoT applications like IOHIVE. With open and freely available LoRaWAN implementations, minimal technical expertise is required to establish such infrastructure, thereby supporting the growth of the project.

Why and how LoRa-based infrastructure can be used for beehive monitoring and journaling.

Apiculture is often practiced in remote areas and over large spatial distances. Typically, intensive apiculture areas are located in non-urban regions where conventional radio technologies, such as cellular or WiFi, are not accessible. Satellite radio technologies, which are available globally, are relatively expensive and require high transmission power, making them unsuitable for low-power IoT systems. Therefore, the use of LoRa and LoRaWAN technologies is being advocated as a solution. The high link budget of LoRa signals allows them to travel long distances and penetrate obstacles commonly found in the apiculture domain, such as high vegetation and landscape geography. The low power requirements for transmitting and receiving messages make it possible to extend the battery life of LoRa-compatible IoT devices or even use energy harvesting techniques. Additionally, setting up a private local LoRaWAN network infrastructure has become effortless. Concentrators are available as standalone devices and can be connected to open-source LNSs deployed on-premises or utilize publicly available open-source and free-to-use LNSs. Furthermore, the availability of public networks deployed worldwide can enable the use of the technology without the need to build a private infrastructure. In other words, LoRa and LoRaWAN infrastructure can be effortlessly used as-is, expanded by collaborating with existing infrastructure or deployed privately on-premises without requiring licensing or pay-per-use schemes.

Hardware used for Wearable, LoRa Sensor Nodes and Gateways.
A common issue of deployed IoT technologies is interoperability of systems and architecture. In order to accommodate this issue, a different approach was required. Journaling and monitoring of apiculture procedure requires both the use of stationary low power IoT devices which can operate autonomously in a harsh environment for long periods of time and the use of high-power wearable devices. Both these different types of systems require different data acquisition, processing and transmission techniques and technologies. Thus, the complexity of developing such a unified system is regarded as high. Sprout IoT platform [36], implemented for the purposed of the IOHIVE project, abstracts the common procedures which differentiate high power wearable devices from stationary low power ones. Two of the main procedures which normally require different design schemes are power management and data transmission. The developed abstraction embedded in the Sprout IoT platform hardware, brings the power consumption and usage schemes and the use of different radio communication technologies to the configuration level allowing for designers and developers to focus on the rest of the application procedure. The end result is a unified platform which can be used in either way without the need to design specific power management and transmission techniques.

IOHIVE Wearable.
The IOHIVE Wearable is a device designed for beekeepers to efficiently journal their beekeeping practices during hive inspections. The device is designed on the basis of the following user requirements and design specifications: a) Sprout-based: The wearable is built upon the versatile Kudzu Sprout platform, ensuring compatibility and seamless integration with other Sprout-based devices, such as scales, b) Rechargeable Battery: The device operates on a rechargeable battery, promoting eco-friendliness and cost-effectiveness with many hours of operation in the field, c) Wi-Fi Connectivity: The wearable supports Wi-Fi uplink and downlink for real-time data transmission, allowing beekeepers to sync their journal entries quickly and easily with the IOHIVE app, d) LoRa and LoRaWAN Compatibility: The wearable is designed to work with LoRa and LoRaWAN technology, enabling long-range, low-power com-

munication for remote connectivity, e) NFC Scanner: Equipped with an NFC scanner, the wearable can quickly read information from NFC tags, streamlining data collection from the beehives, f) User Interface: The intuitive UI includes buttons, LEDs, a rotary encoder, and a screen, facilitating smooth navigation and interaction for beekeepers, g) User-Friendly Design: With a focus on usability and wearability, the IOHIVE Wearable ensures comfort and functionality, making it an indispensable tool for beekeepers, h) Dedicated Software: The device's software is tailored for beekeeping inspections, providing a comprehensive and efficient solution for monitoring and managing hives. Throughout the development process, the IOHIVE Wearable has undergone various prototyping stages. In the following figures we provide CAD models and images of the 3D-printed prototypes that showcase the evolution of the design, including the electronics and circuits, to offer a detailed insight into the wearable's creation. The CAD models of the IOHIVE Wearable's design are readily available on our online IOHIVE Digital Repository [34], which we update frequently to showcase the latest advancements and improvements in the open design process.

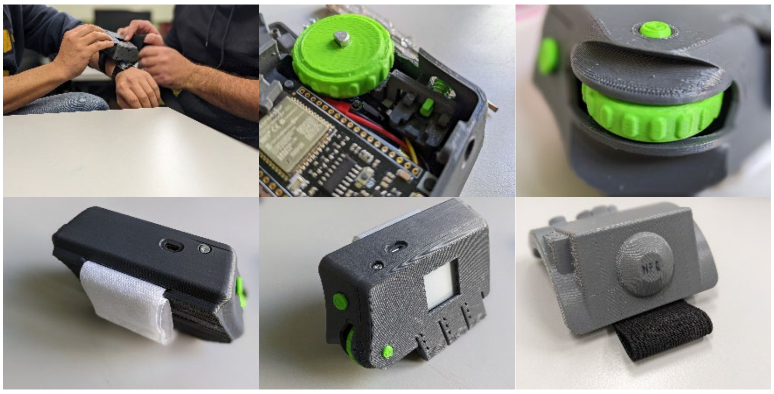


Fig. 8.

LoRa Sensor Nodes and Gateways.

Devices (nodes and gateways) used in this project utilize LoRa low-power wide-area network modulation. Some node devices, supporting 3G/4G, communicate via SMS technology, ensuring coverage in areas with limited LoRa access. The aim is to install low power LoRa nodes in apiaries, connecting to the nearest LoRa gateway [37, 38]. The gateways relay data to The Things Network [33]. Utilising suitable payload decoders and webhooks, the payload is supplemented with a unique device ID and timestamp, and subsequently conveyed to the IOHIVE Service.

3.3 Sensors & Weather Stations

The IOHIVE platform boasts an open and extensible architecture, deliberately crafted to facilitate the integration of diverse end devices. It is hardware-agnostic, meaning that it allows for the integration of end devices, regardless of their manufacturer, model, or specifications. IOHIVE's core role is to facilitate remote beehive monitoring, collection of weather and environmental data, and inspection data. Metrics such as a) hive weight, b) internal/external hive temperature, c) humidity and d) internal hive sound offer critical insights into bee colony status. Broad area climatic and apiary-specific microclimatic data serve as valuable environmental indicators. Furthermore, beehive inspection data, supplied by beekeepers, presents an invaluable additional information layer. This empirically derived data, rooted in observation and experience, offers a subjective measure of phenomena as experienced firsthand by the beekeepers. The significance of this data is undeniable, and it can be further employed in correlating with sensor-derived data. An overview of the end devices already integrated into the platform is provided in the subsequent figures:

Fig. 9. IOHIVE end devices. a) BEEP base, b) SaveBees SMS scale, c) Kudzu scale based on Sprout, and d) MeteoHelix IoT Pro weather station MeteoWind IoT Pro wind sensor.

4 Advantages and future directions

IOHIVE presents a novel approach aimed at enhancing apiculture-related activities by promoting sustainable beekeeping practices through the use of digital technologies for monitoring and journaling. These practices aid in conserving bees as essential pollinators while also fostering the economic viability of the beekeeping community. The IOHIVE approach provides scalability, security, interoperability, and decentralisation for large-scale IoT deployments for smart and precision apiculture. Future directions for research and development will focus on evaluating the wearable/tangible device, improve the design and UX of the GUIs of the web appplication, expanding network coverage through optimized network planning and deployment, integrating AI and data analytics, developing standards and protocols for beekeeping, and optimizing costs through cloud-based solutions and automation.

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References

1. Howard, S.R., Ratnayake, M.N., Dyer, A.G., Garcia, J.E., Dorin, A.: Towards precision apiculture: Traditional and technological insect monitoring methods in strawberry and raspberry crop polytunnels tell different pollination stories. PLOS ONE. 16, e0251572 (2021).
2. Hadjur, H., Ammar, D., Lefèvre, L.: Toward an intelligent and efficient beehive: A survey of precision beekeeping systems and services. Computers and Electronics in Agriculture. 192, 106604 (2022).
3. Zacepins, A., Brusbardis, V., Meitalovs, J., Stalidzans, E.: Challenges in the development of Precision Beekeeping. Biosystems Engineering. 130, 60–71 (2015).
4. Bourouis, A., Benahmed, T., Mokeddem, K.A.M., Benahmed, K., Lairedj, A.S.: IoT for Smart Apiculture: Issues and Solutions. In: 2022 3rd International Conference on Embedded & Distributed Systems (EDiS). pp. 61–66 (2022).
5. González Pacheco, M.A., Barragán Ocaña, A.: Sustainability and Innovation in the Beekeeping Sector: A First Approach. In: Estrada, S. (ed.) Digital and Sustainable Transformations in a Post-COVID World: Economic, Social, and Environmental Challenges. pp. 161–189. Springer International Publishing, Cham (2023).
6. Abu, E.S.: The use of smart apiculture management system: review paper. Asian Journal of Advances in Research. 6–16 (2020).
7. Zacepins, A., Kviesis, A., Pecka, A., Osadcuks, V.: Development of Internet of Things concept for Precision Beekeeping. In: 2017 18th International Carpathian Control Conference (ICCC). pp. 23–27 (2017).
8. Dasig, D.D., Mendez, J.M.: An IoT and Wireless Sensor Network-Based Technology for a Low-Cost Precision Apiculture. In: Pattnaik, P.K., Kumar, R., and Pal, S. (eds.) Internet of Things and Analytics for Agriculture, Volume 2. pp. 67–92. Springer, Singapore (2020).
9. Ochoa, I.Z., Gutierrez, S., Rodríguez, F.: Internet of things: Low cost monitoring beehive system using wireless sensor network. In: 2019 IEEE International Conference on Engineering Veracruz (ICEV). pp. 1–7. IEEE (2019).
10. Tashakkori, R., Hamza, A.S., Crawford, M.B.: Beemon: An IoT-based beehive monitoring system. Computers and Electronics in Agriculture. 190, 106427 (2021).
11. Chamaidi, T., Malisova, K., Nomikos, V., Vlachogiannis, E., Alifieris, C., Rigakis, C., Stavrakis, M.: IOHIVE: Design Requirements for a System that Supports Interactive Journaling for Beekeepers During Apiary Inspections. In: Soares, M.M., Rosenzweig, E., and Marcus, A. (eds.) Design, User Experience, and Usability: UX Research, Design, and Assessment. pp. 157–172. Springer International Publishing, Cham (2022).
12. Zabasta, A., Kunicina, N., Kondratjevs, K., Ribickis, L.: IoT Approach Application for Development of Autonomous Beekeeping System. In: 2019 International Conference in Engineering Applications (ICEA). pp. 1–6 (2019).

13. Sperandio, G., Simonetto, A., Carnesecchi, E., Costa, C., Hatjina, F., Tosi, S., Gilioli, G.: Beekeeping and honey bee colony health: A review and conceptualization of beekeeping management practices implemented in Europe. Science of The Total Environment. 696, 133795 (2019).
14. Durant, J.L., Ponisio, L.C.: A Regional, Honey Bee-Centered Approach Is Needed to Incentivize Grower Adoption of Bee-Friendly Practices in the Almond Industry. Frontiers in Sustainable Food Systems. 5, 261 (2021).
15. BEEP: digital tools for beekeepers, https://beep.nl/index.php/home-english, last accessed 2022/02/11.
16. OSBeehives - BuzzBox Hive Health Monitor & Beekeeping App, https://www.osbeehives.com, last accessed 2022/02/11.
17. beeXML.org – Collaboration platform for the standardization of the exchange of data about bees and beekeepers – BeeXML, https://beexml.org/beexml/, last accessed 2022/01/30.
18. Hodzic, A., Hoang, D.: Detection of Deviations in Beehives Based on Sound Analysis and Machine Learning. (2021).
19. Terenzi, A., Cecchi, S., Spinsante, S.: On the Importance of the Sound Emitted by Honey Bee Hives. Veterinary Sciences. 7, 168 (2020).
20. Kulyukin, V., Mukherjee, S.: On Video Analysis of Omnidirectional Bee Traffic: Counting Bee Motions with Motion Detection and Image Classification. Applied Sciences. 9, 3743 (2019).
21. Spiesman, B.J., Gratton, C., Hatfield, R.G., Hsu, W.H., Jepsen, S., McCornack, B., Patel, K., Wang, G.: Assessing the potential for deep learning and computer vision to identify bumble bee species from images. Sci Rep. 11, 7580 (2021).
22. Campbell, J., Mummert, L., Sukthankar, R.: Video Monitoring of Honey Bee Colonies at the Hive Entrance. 4 (2008).
23. Chen, C., Yang, E.-C., Jiang, J.-A., Lin, T.-T.: An imaging system for monitoring the in-and-out activity of honey bees. Computers and Electronics in Agriculture. 89, 100–109 (2012).
24. Tu, G.J., Hansen, M.K., Kryger, P., Ahrendt, P.: Automatic behaviour analysis system for honeybees using computer vision. Computers and Electronics in Agriculture. 122, 10–18 (2016).
25. Aumann, H.M., Aumann, M.K., Emanetoglu, N.W.: Janus: A Combined Radar and Vibration Sensor for Beehive Monitoring. IEEE Sensors Letters. 5, 1–4 (2021).
26. Schurischuster, S., Remeseiro, B., Radeva, P., Kampel, M.: A Preliminary Study of Image Analysis for Parasite Detection on Honey Bees. In: Campilho, A., Karray, F., and ter Haar Romeny, B. (eds.) Image Analysis and Recognition. pp. 465–473. Springer International Publishing, Cham (2018).
27. Hadjur, H., Ammar, D., Lefèvre, L.: Analysis of energy consumption in a precision beekeeping system. In: Proceedings of the 10th International Conference on the Internet of Things. pp. 1–8. Association for Computing Machinery, New York, NY, USA (2020).

28. Rahman, A.B.M.S., Lee, M., Lim, J., Cho, Y., Shin*, C.: Systematic Analysis of Environmental Issues on Ecological Smart Bee Farm by Linear Regression Model. IJHIT. 14, 61–68 (2021).
29. Kulyukin, V.: Audio, Image, Video, and Weather Datasets for Continuous Electronic Beehive Monitoring. Applied Sciences. 11, 4632 (2021).
30. Tashakkori, R., Hamza, A.S., Crawford, M.B.: Beemon: An IoT-based beehive monitoring system. Computers and Electronics in Agriculture. 190, 106427 (2021).
31. Zacepins, A., Kviesis, A., Pecka, A., Osadcuks, V.: Development of Internet of Things concept for Precision Beekeeping. In: 2017 18th International Carpathian Control Conference (ICCC). pp. 23–27 (2017).
32. Kontogiannis, S.: An Internet of Things-Based Low-Power Integrated Beekeeping Safety and Conditions Monitoring System. Inventions. 4, 52 (2019).
33. The Things Network, https://www.thethingsnetwork.org/, last accessed 2023/04/11.
34. IOHIVE Project Website and Services, https://iohive.aegean.gr, last accessed 2023/04/11.
35. Adelantado, F., Vilajosana, X., Tuset-Peiro, P., Martinez, B., Melia-Segui, J., Watteyne, T.: Understanding the Limits of LoRaWAN. IEEE Commun. Mag. 55, 34–40 (2017).
36. Kudzu P.C., https://kudzu.gr/, last accessed 2022/02/11.
37. Sinha, R.S., Wei, Y., Hwang, S.-H.: A survey on LPWA technology: LoRa and NB-IoT. ICT Express. 3, 14–21 (2017).
38. Bor, M., Vidler, J.E., Roedig, U.: LoRa for the Internet of Things. Presented at the EWSN ’16 Proceedings of the 2016 International Conference on Embedded Wireless Systems and Networks , AUT February 15 (2016).