Digital support platform for beekeepers

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Jean-Charles HUET[1] , Lamine BOUGUEROUA[1] , Yassine KRIOUILE[1] , Alexandre DANGLEANT[2] , Axel DECOURTYE[2] , Constance BERI[2] , Adèle BIZIEUX[3] , Elodie RUMIANO[3] , Lucille JOHANNET[4] , Alicia TESTON[4] , Pascal JOURDAN[5] , Coline KOUCHNER[5]

[1] Efrei Research Lab, Université Paris-Panthéon-Assas, 30-32 avenue de la République, 94800 Villejuif, France

[2] Institut Technique et Scientifique de l'Abeille et de la Pollinisation (ITSAP), INRAE, Unité de Recherche 406 Abeille & Environnement, 228 route de l'Aérodrome, 84914 Avignon, France

[3] Association de Développement de l'Apiculture en Auvergne-Rhône-Alpes (ADA AURA), Chambre Régionale d'Agriculture, 9 allée Pierre de Fermat, 63170 Aubière, France

[4] Association de Développement de l'Apiculture en Nouvelle-Aquitaine (ADANA), 3 boulevard Vladimir, 17100 Saintes, France

[5] Association de Développement de l'Apiculture en Provence (ADAPI), Maison des Agriculteurs, 22 Avenue Henri Pontier, 13626 Aix en Provence, France

Correspondence : jean-charles.huet@efrei.fr

Abstract

Beekeeping becomes technically more complex, due to the drop in harvests and the loss of livestock that negatively influence this activity. Scientific and technical references remain insufficiently transferred to all beekeepers. This is partly due to a lack of data collected under real beekeeping conditions. We are proposing to build digital tools for managing bee populations, providing back-up for beekeeping practices, colony health and yield, while enabling beekeepers to compare their data. The aim of the tools developed is to support beekeepers in their decision-making. More practically, these tools include a digital logbook, a data entry application and a varroa mite detection tool.

Keywords : Beekeeping management, Decision support tools, Artificial intelligence, Precision beekeeping, Image processing, Chatbot, Varroa mite,

Introduction

Over the last twenty years or so, the beekeeping industry has been faced with a sharp drop in honey yields per colony on farms, which is having a serious impact on their productivity and sustainability. In fact, honey production in France has fallen from an all-time high of 33,000 tonnes per year (reported in 1995) to 15,000 tonnes in 2013, despite the number of hives remaining constant (Dangleant *et al.,* 2021). The more favourable year of 2015, with production of 24,000 tonnes, was unfortunately followed by a complicated year in 2016 (16,000 tonnes produced), for which the yield per hive fell by 37% to 16.5 kg/hive compared with 26.3 kg/hive in 2015 (FranceAgriMer, 2016). For the record, national honey consumption is considered to be stable at 40,000 tonnes per year. French honey production does not cover national consumption. The balance of trade is in deficit, at €80 million per year between 2014 and 2020 (FranceAgriMer, 2022a). The estimated yield for 2021 is 14 kg/hive, 39.6% less than in 2020. This is the lowest level recorded since the start of the FranceAgriMer observatory (FrancerAgriMer, 2022b).

This low production is accompanied by numerous cases of weakening and loss of colonies both in season and in winter. Indeed, the national winter mortality rate is higher each year than the threshold considered acceptable by the profession (10%), with 25% for the period 2008 - 2011, 18.4% in 2012, 17.3% in 2013 (Decourtye and Vallon, 2015), 13.7% in 2014 (European Epilobee Project) and 13.4% in 2015 - 2016

(Brodschneider *et al*., 2016). Added to this are in-season mortalities, a phenomenon that appeared in the 1990s and affected around 13.6% of farm livestock in France between 2012 and 2013, which is the highest rate in Europe (European Epilobee Project).

Beekeepers are now benefiting from significant technological advances to assist them in the technical management of their livestock, particularly with the widespread use of automatic scales. Despite the emergence of computerised systems for recording data on beekeeping, the computerisation of data by beekeepers themselves seems to remain a marginal practice. To date, the apiary notebook remains the most widely used tool, with the most important data also recorded on the roof of the hives. The history of a colony is therefore difficult to consult, and beekeepers' references are empirical.

The project presented here provides a very practical response for beekeepers, helping them to manage their data more effectively on a daily basis. Better control of this data means a better ability to select their stock and favour the most resistant colonies adapted to their activity and environment. This is all the more true in the context of centralisation, which will enable professionals to position themselves in relation to each other and identify efficient practices.

The inclusion of beekeeping development organisations in the design of the platform will serve the objective of setting up a new vector for the transfer of knowledge and expertise, and will pave the way for better local coordination. Lastly, the emergence of an unprecedented repository resulting from participatory science will represent a new field of analysis for research structures.

The aim of our project "Plateforme Numérique d'accompagnement des APIculteurs" (PNAPI - Digital Support Platform for Beekeepers) is to provide beekeepers with IT tools that will give them a better overview of their beekeeping practices and the characteristics of their colonies, save them time entering data and make it easier for them to manage their livestock. In addition, they will have access to environmental data, personalised and more precise support over time from development structures and they will also be able to position themselves in relation to beekeepers on a regional or national scale, depending on their practices and specialisation.

Through this platform, development structures will benefit from modern, effective tools for reporting events to beekeepers, detecting the emergence of problems in apiaries at an early stage and alerting beekeepers located in the risk zone much more quickly and effectively than is currently the case. A *voicebot* application has also been developed to feed this platform and help beekeepers enter their data alongside the hive, despite the equipment. The final tool we want to make available to beekeepers is a varroa mite detection system based on image analysis.

These IT tools form part of the ecosystem of applications in which ITSAP (Institut Technique et Scientifique de l'Abeille et de la Pollinisation - Technical and Scientific Institute for Bees and Pollination) has played an active part in developing, such as the two applications : VarroAppli and BeeGIS. The first involves collecting and pooling the varroa mite surveys carried out by the network's beekeepers and agents, to enable beekeepers to position themselves in relation to local averages. The second is a summary of land use in the foraging area of an apiary.

The aim of the PNAPI project, led by ITSAP, was to develop IT tools to support beekeepers in their practices. More specifically, the aim was to (1) collect needs based on a survey of beekeepers, (2) develop a digital platform to meet these needs, (3) develop a *voicebot* to feed this platform with data from the hives and (4) propose a tool for analysing varroa mite disease based on image analysis using Artificial Intelligence (AI).

Methods

The working method implemented within each action is consistent with this "inter-action" logic. In fact, the digital platform is being developed using the AGILE method[1] , which favours short development cycles and encourages exchanges between the project owner and the project manager. In the context of the PNAPI project, the project owner is the "business" Working Group (WG) formed by ITSAP - Institut de l'abeille and the project's partner Beekeeping Development Associations (ADA in French: Auvergne Rhône Alpes, Nouvelle Acquitaine and Provence). The business working group is responsible for identifying the expectations of beekeepers and formulating them in terms of functionalities to be developed. These expectations are then set out in an interface proposal for the project manager, represented by the partner EFREI (engineering school of digital technologies). The latter assesses the proposals, develops them and then puts the result online so that the working group can carry out tests and give feedback on the new additions. This work is carried out cyclically, page by page.

The "business" working group carried out an online survey as a basis for gathering the needs of beekeepers. The online survey was initially designed in the form of a mind map (XMIND© software) in order to define, first of all, the themes to be addressed in a general way, and then more and more precisely until the questions and response formats were defined.

The online survey questionnaire was then transposed using Google Forms by ITSAP. The ADAs and ITSAP then distributed it to their beekeepers using their traditional communication channels (social networks, newsletter, websites). The result of the survey was an Excel table containing the responses. This data table was analysed using R software (R Core Team, 2023) to produce graphs showing the results concerning beekeepers' expectations. The face-to-face surveys consisted of working sessions with beekeepers and ADA and ITSAP agents. First of all, a round table discussion was held to describe how each farm operated. These descriptions were transcribed in the form of a mind map in order to organise the information given by the beekeepers according to the different workshops on their farm. Particular attention was paid to the life cycle of the data (collection, analysis, definition of actions, etc.) for each type of beekeeping activity.

The test sessions were carried out in webinars with the beekeepers following the project on the one hand, and with the agents of our ADA - ITSAP network on the other (including the ADAs that are not partners in the project). Another session was held at the "Tech&Bio" beekeeping trade show in September 2021[2] .

For these test sessions, exercises and questionnaires were prepared in advance by the business working group.

Results

3.1 Identifying needs

This stage enabled us to identify user needs, define typical data life-cycle profiles for beekeeping operations, conceptualise the functions and interfaces to be developed and gather feedback on the development of the platform prototype.

These results can be translated into resources that can be mobilised for development, starting with the feedback from the online survey: 440 beekeepers responded to the survey. The profiling questions made it possible to establish a good representation of the size of the livestock and the types of beekeeping

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[1] Manifesto for Agile Software Development, https://agilemanifesto.org/iso/fr/manifesto.html, available on 17 May 2024

[2] International agricultural fair for organic and alternative techniques, organised in Drome, France: https://www.tech-n-bio.com/fr/archives-1/salon-international-techbio-2021/ce-qui-vous-attend, accessible to 17 May 2024

activities carried out by the respondents. This diversity, together with the number of responses received, enabled us to build a solid basis for our work on beekeepers' expectations. The results of this survey have been used to draw up graphs showing the expectations of the target audiences according to their operator profile. An example of this type of production is shown in Figure 1.

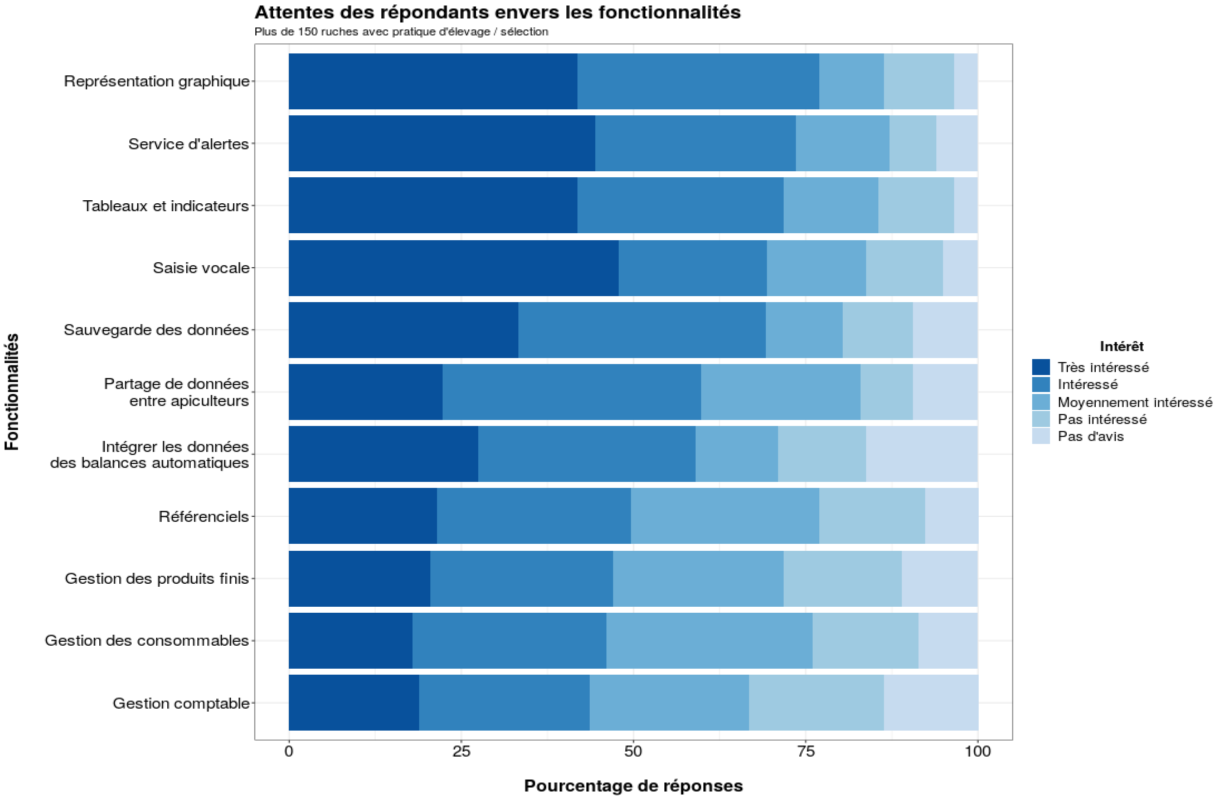

Figure 1 Expectations of respondents to the online survey concerning a livestock management platform according to their number of hives and type of activity (here: breeders with more than 150 hives). Translation of the French terms at the end of the article.*

The face-to-face surveys identified the cycle and use of data within the farms. The resources produced consist of mind maps representing the characteristics and workings of the farmers who took part. This type of resource is illustrated in Figure 2 .

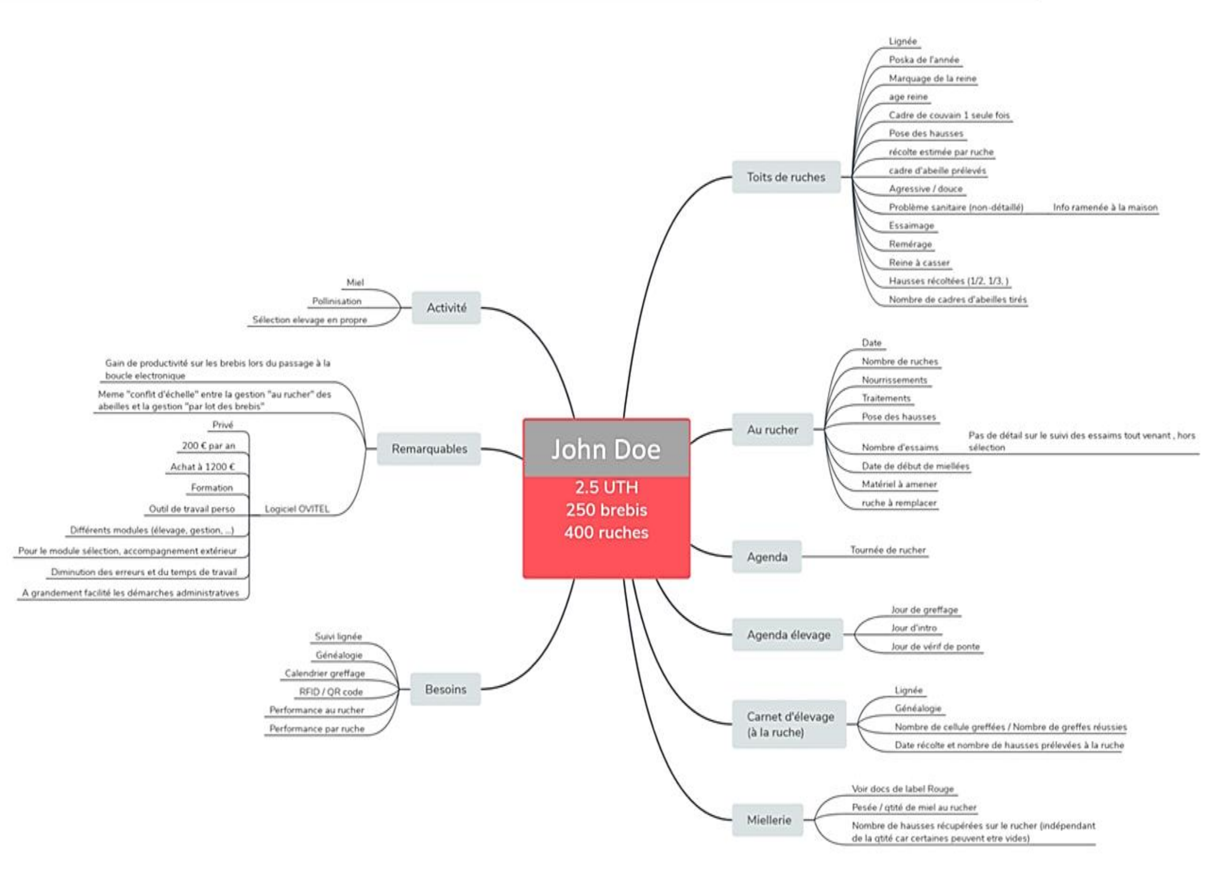

Figure 2 Heuristic map of an anonymised surveyed beekeeper, representing the characteristics and operation of this beekeeping's system. The map was produced using XMind© software based on a face-to-face survey.

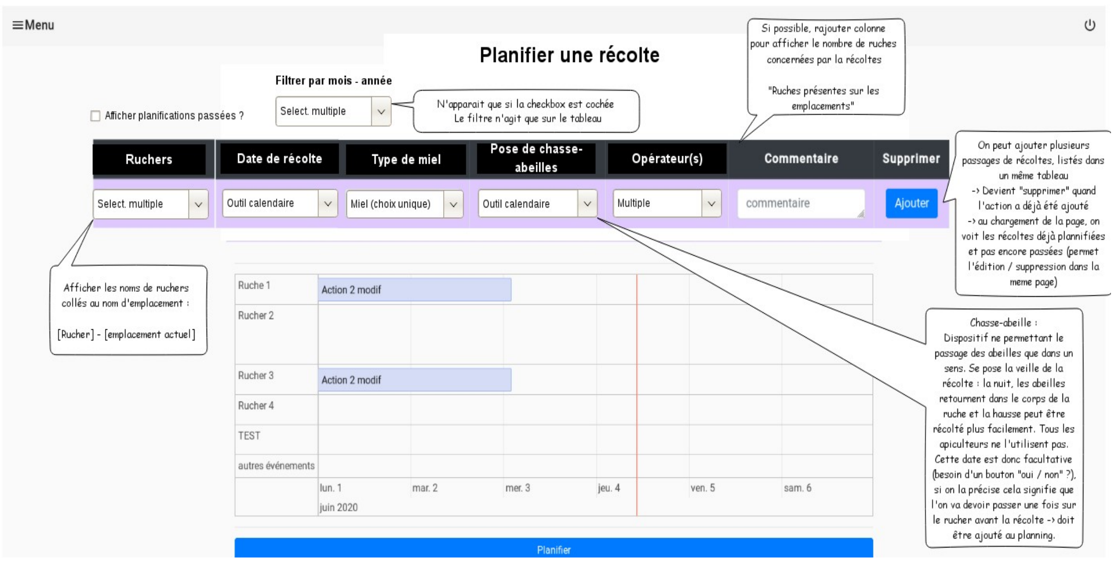

Figure 3 Example of a mock-up, relating to the planning of honey harvesting on the PNAPI platform. In this interface, the user is confronted with to enter the characteristics of his system. Translation of the French terms at the end of the article.*

Finally, crash tests carried out in workshops with beekeepers helped to identify areas for improvement in our interfaces. During these workshops, a short presentation was given to remind participants of the project's objectives and clarify what was expected of them. An exercise was then proposed, asking for different actions to be carried out on the interface (creating hives, declaring transhumance, etc.). The interface was not presented prior to the exercise, so that the beekeepers could discover it on their own, to avoid confusing them. Feedback was then collected by means of a questionnaire, followed by a free discussion period.

The main objective of this work was to contribute to the development of the PNAPI digital platform. This took the form of conceptual mock-ups of the interface, as illustrated in Figure 3.

These models and the intermediate results that were used to build them, i.e. the heuristic maps of the farms and the results of the online survey, are valuable resources. Beyond the project, they are useful for all the digital tool developments that ITSAP is undertaking, for the beekeeping research and development network and for beekeepers themselves. They can also be used to respond more effectively to requests from institutional partners such as ANSES.

3.2 Applications developed: digital platform

At the end of this project, here are the results obtained as part of the development of a platform for beekeepers:

- A database adapted to the business objects linked to beekeeping practices, scalable thanks to its flexible structure (NoSQL) and capable of managing a large amount of data (**Figure** 4),
- Web services that enable the platform to communicate with the database,
- A prototype of the platform with numerous functionalities relating to different aspects of livestock management, such as the planning and recording of various actions in the apiary (creation of hives, transhumance, harvests, anti-varroa treatment strategies and actions, etc.).

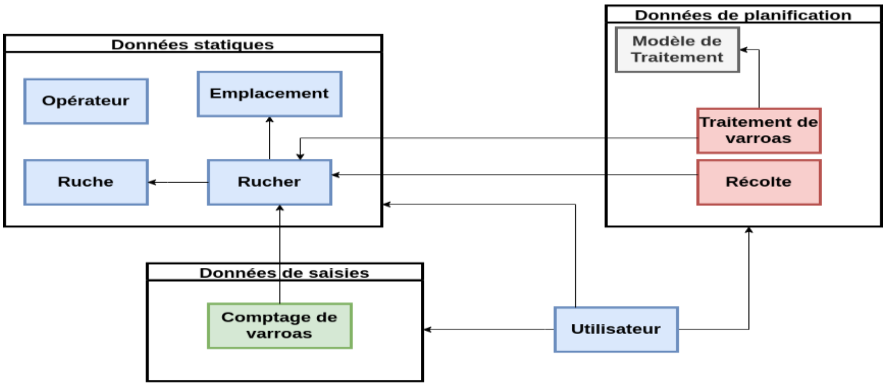

Figure 4 Database structure. Translation of the French terms at the end of the article.*

All the features developed are shown on the diagram below (Figure 5).

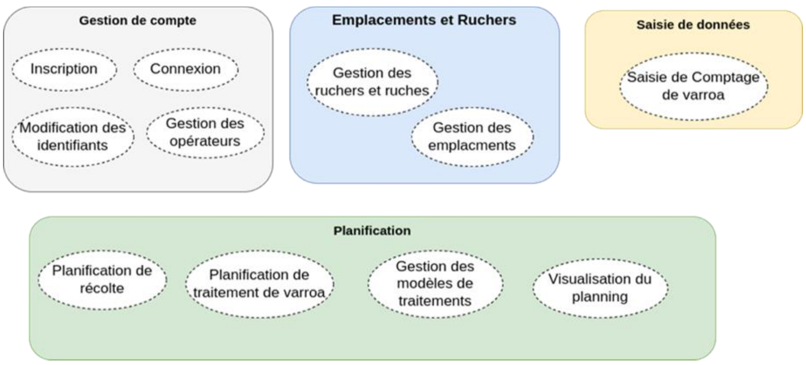

Figure 5 Application features. Translation of the French terms at the end of the article.*

The *framework* used to develop the platform is Angular[3] . This framework enables web development as well as automated transcription of the web interface to a mobile version (Android). The database is of the NoSQL type, the database management system being MongoDB. Code versions, feature requests and bug reports were tracked using Gitlab.

Firstly, the platform prototype allows hives to be created in batches, organised into apiaries to be positioned in locations (Figure 6). The ability to generate an apiary with 40 hives (for example) in just a few clicks is a major advantage for beekeepers with several hundred colonies. The prototype also makes it possible to create one (or more) operator(s) attached to the user's main account. This functionality can also be used to restrict data read and/or write rights, and to provide time-limited access to manage the use of the application by seasonal beekeepers. The locations on which the apiaries are positioned can also be labelled by the user to define the type of activity possible on this geographical site (wintering, lavender honeyflow, etc.). These labels make it easier to filter locations and apiaries in the various interface menus.

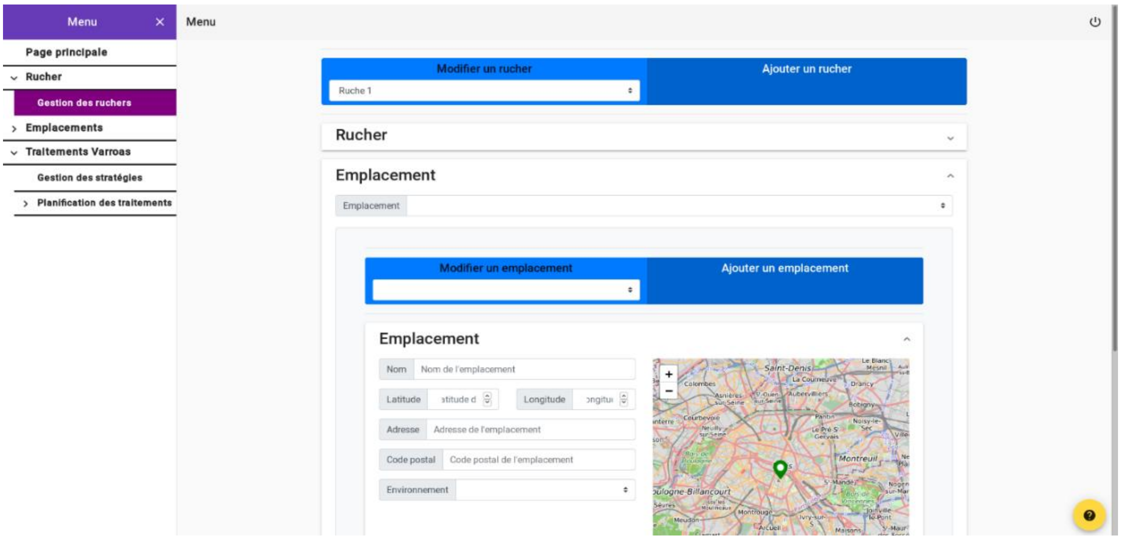

Figure 6 Screenshot of the apiary creation and location screen from the PNAPI platform prototype. Translation of the French terms at the end of the article.*

For each apiary, the PNAPI application can be used to plan a wide range of actions, specifying the operator in charge of them. These actions correspond to interventions in the field to harvest honey, apply an anti-Varroa treatment, carry out a Varroa survey (on lange or phoretic), or carry out a transhumance. Depending on the type of action, a list of the equipment needed in the field is suggested based on information specific to the intervention.

In the case of harvesting, transhumance and Varroa counts, the planning interfaces have a similar structure with:

- Multiple-choice drop-down menus for selecting the operators and apiaries to be used,
- A list of actions already planned for the apiary,
- A calendar tool to specify the date of the intervention,
- A timeline showing the actions already planned for all the apiaries selected during the week,
- A button to save the schedule,
- A menu enabling you to select a schedule that has already been created and modify it.

[3] Angular: https://angular.io/, available on 17 May 2024

Actions relating to varroa treatments involve a sequence of interventions on the apiary in question. The planning interfaces are similar to those described above, except that the date entered by the user corresponds to the start date of the sequence, which is selected from a single-choice drop-down menu. The sequences themselves can be configured on a dedicated page called "Varroa control strategy".

In the case of varroa treatments, the page consists of a single-choice menu allowing you to select a strategy that has been pre-entered (with a Marketing Authorisation) by the business working group. The interventions corresponding to the strategy are then listed in a table, specifying the interval between interventions (in Julian days), as well as the equipment required for the intervention. These strategies can be configured, and the user can re-use a pre-entered template (without deleting or permanently modifying the standard templates) to add his or her own actions. For example, they can add a run of oxalic acid x days after the last action in the sequence.

Once the work has been carried out in the field, the user is notified when the plans have expired and encouraged to enter the relevant information on the dedicated pages. These pages are therefore specific to the actions in question, whether it's to enter a honey harvest, a varroa mite count (on lange or phoretic), feeding, etc. As well as collecting data, the aim of these pages is to validate that the action in the field has actually taken place. In fact, beekeepers are subject to unforeseen circumstances that affect their planning, whether due to unfavourable weather, the early start of honeyflow, or to compensate for losses during the season. The risk of incorrect declarations on the platform in these circumstances should therefore be avoided.

Finally, the application's home page consists of a calendar listing all the actions planned. Each action is represented by a label indicating the nature of the operation, the apiary in question and the operator in charge. Clicking on the label opens a box in the margin with additional information, such as the list of equipment required to carry out the operation and any comments entered by the user.

The last task, synchronising the storage space, is theoretically functional because of the technological choices made. However, these could not be tested in a real-life situation because the smartphone version of the platform prototype was not deployed due to time constraints.

3.3 BeeKnot: VoiceBot for beekeepers

The work on the voice input assistant had to be carried out in parallel with the development of the platform. In fact, the precise identification of the information expected by the user during use in the apiary came too late to allow this functionality to be integrated into the platform prototype, especially as the Android version has not yet been deployed. Voice recognition was nevertheless developed for research purposes, in order to test the possibilities of adapting the technology to the noise conditions of an apiary. Typical recordings were simulated by adding sound recordings of the environment over the user's voice. The work carried out was presented by EFREI to the steering committee at the final meeting of the project and highlighted the feasibility of voice input in the apiary. Since the end of the project, EFREI has continued to work on the development of this *Voicebot* (Ahmed *et al.*, 2023). A conceptual architecture, shown in Figure 7 has been implemented.

The solution is based on four main groups of components:

- **Intelligent natural language processing (NLP) systems**: These systems mainly provide us with all the tasks relating to the processing and understanding of the beekeeper's natural language that we will need in our system to achieve the desired functionalities.
- **Voice keyword detector**: This system ensures a hands-free experience by triggering the three use cases linked to voice commands (record, confirm and cancel) by saying predefined key words.
- **Cloud-based database management system (DBMS)**: Cloud storage is crucial in our system to ensure that beekeepers' orders are kept up to date.

- **Mobile application**: The Android application to be developed will enable beekeepers to easily exploit the functionalities by providing them with an easy-to-use interface for communicating with the intelligent ChatBot.
- **APIs**: These APIs act as a gateway, providing a web portal for communicating with the AI systems and the DBMS.

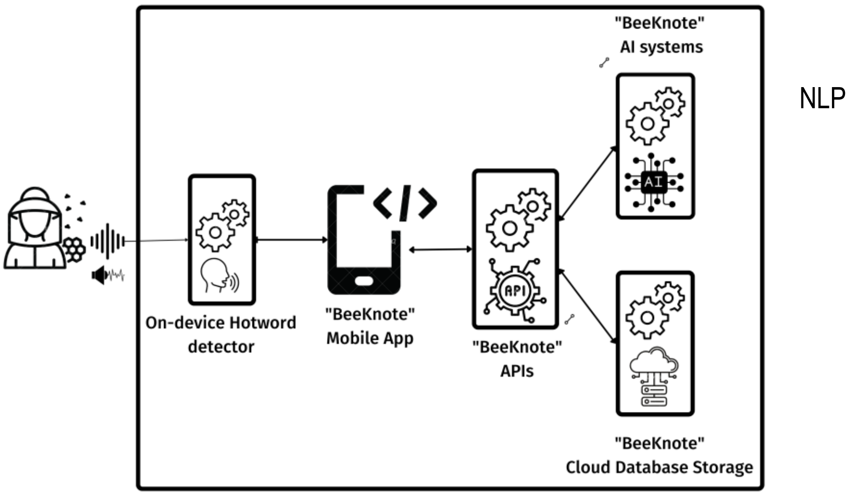

Figure 7 Conceptual architecture of the BeeKnot *VoiceBot* solution developed as part of the PNAPI project. APIs: Application Programming Interface; NLP: Natural Language Processing, a technology that makes it possible to understand human language; DBMS: Database Management System. Figure from (Ahmed *et al*., 2023).

The Figure 8 shows a demonstration of the chatbot.

3.4 <u>Detecting bees and varroa mites</u>

Part of the project also involved detecting bees and varroa mites from the images. This gave rise to a doctoral thesis (Kriouile, 2022). Various approaches have been proposed in the state of the art, but the main limitations of these approaches are the use of specific equipment in the hive, failure to deal with cases of occlusion, intrusive methods in relation to the bees and the non-realistic images used.

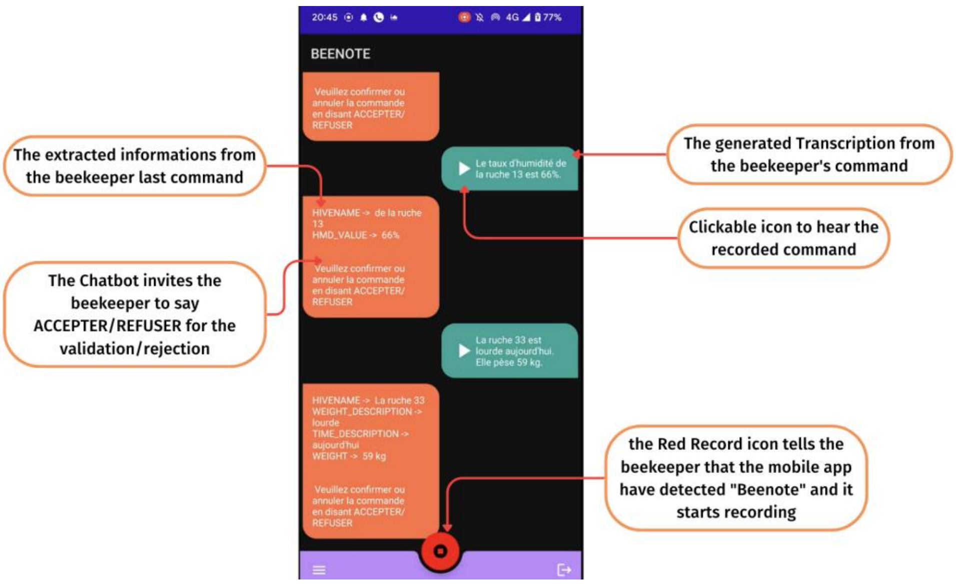

Figure 8 *Chatbot* interface

For the detection of nested objects, the standard approach consists of successive object detection. This is based on the use of two neural networks, each trained to find the positions of a given type of object. This approach lacks efficiency because features are extracted twice from the same image.

In this research work, we proposed to extend the Faster R-CNN neural network (Shaoqing *et al.*, 2016) to improve the detection of nested objects in dense scenes. The approach is enhanced by an application of bee and varroa detection using an annotated bee frame image base.

Our proposals resulted in a neural network that improved varroa detection by 1.9% in terms of accuracy, with no loss of bee detection accuracy compared with consecutive detection. We also succeeded in producing a network that improves varroa detection accuracy by 11% compared with standard feature extraction.

To train and evaluate our approaches, we built a database of images annotated with bees and varroa mites: 63 bee frame images, 3863 annotated bees, 565 annotated infected bees and 638 annotated varroa mites (see Figure 9 to Figure 11).

We used three different tools to annotate our images. The first is Imagetagger[4] (Figure 9), a web application connected to a server for annotating images with bounding boxes. This tool enabled us to work remotely in collaboration with our partners. We installed it and configured it so that it could be accessed via the Internet. Our project partners used it to help us with the annotation task. The second tool is the Matlab Image Labler application[5] (Figure 10). Using this tool, we annotated some of the images in our database with bounding boxes and then exported the annotations to the Matlab workspace. Matlab code was developed to export the annotations from Matlab format to Json format. This tool has the advantage of being easy to use. We also used the "Via annotator tool"[6] to annotate varroas using ellipses. This is a web application that does not require installation. We developed a python application for detecting bees and varroa mites (Figure 11).

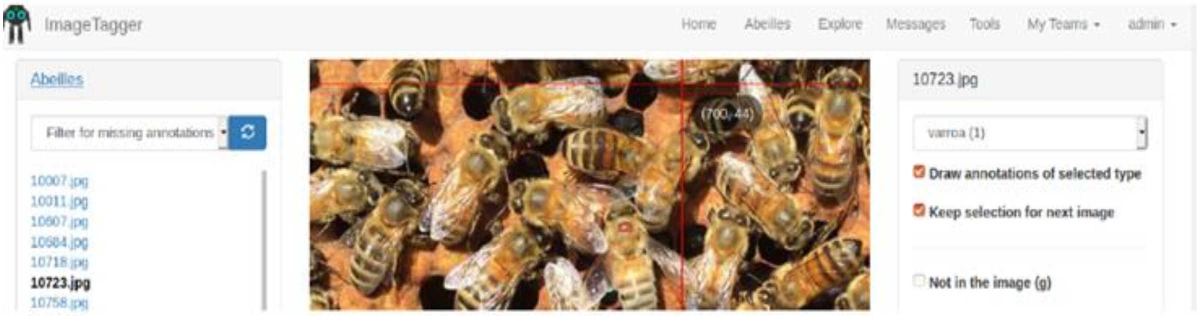

Figure 9 Annotation images

[4] https://github.com/bit-bots/imagetagger, accessible on 17 May 2024

[5] https://fr.mathworks.com/help/vision/ref/imagelabeler-app.html, accessible on 17 May 2024

[6] https://www.robots.ox.ac.uk/~vgg/software/via/, available on 17 May 2024

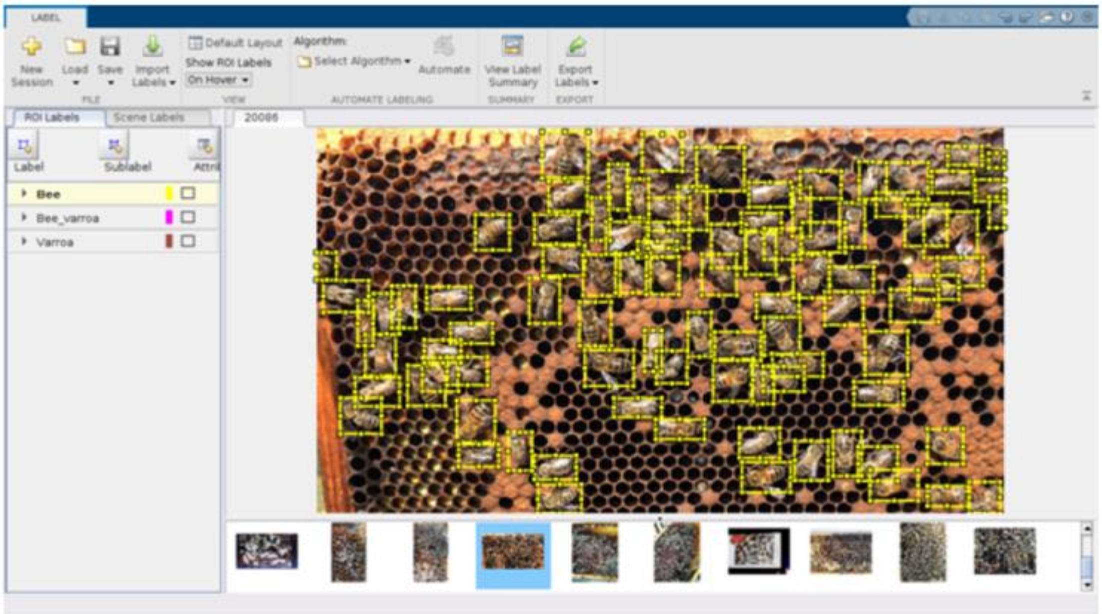

Figure 10 Labelling images

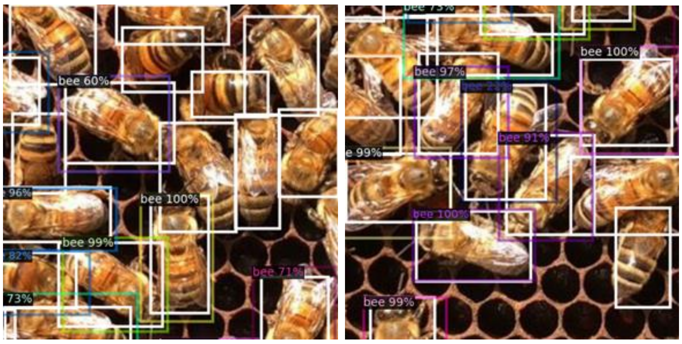

Figure 11 Bee detection in a dense scene

Here is the list of major contributions in this field:

- Construction of a database of images annotated by bees and varroa mites: 63 images of bee frames, 3863 annotated bees, 565 annotated infected bees and 638 annotated varroa mites,
- New method for detecting nested objects in dense scenes (using extended Faster R-CNN deep learning),
- Detecting objects by their corners, with new annotation data, four additional branches to RPN (Region Proposal Network) (Shaoqing *et al.*, 2016) for object detection from the different corners of an object:
  - In the case of bee detection in dense scenes: 10% improvement in recall and 6% improvement in precision,
  - We applied our method to the detection of people in dense scenes, improving precision and recall by 3%,
- Use of a Mask R-CNN **(**Regions with Convolutional Neural Networks) neural network (He *et al.,* 2018) for one-shot detection of nested objects, in our case, bees and varroa mites:
  - 1.9% improvement in varroa detection accuracy with no loss of bee detection accuracy compared with consecutive detection.
  - 11% improvement in varroa detection accuracy compared with standard feature extraction.

4. Conclusion and futur work

The prototypes delivered at the end of this project are:

1. A web portal linked to the smartphone application that will enable hives to be managed and user-related data to be viewed more widely.
2. A smartphone application for data entry in the apiary, with voice input adapted to the field and management of the absence of a 3G / 4G connection by means of dual storage, local and on a remote server, which can be synchronised. This application will also allow you to view important information in the apiary.
3. It was decided to test the artificial intelligence method for detecting phoretic Varroa mites on bees using image analysis. Ultimately, this technique could consolidate the data collected by VarroAppli.

These IT tools will enable beekeepers to manage their livestock more effectively, circulate event alerts and thus improve production conditions. They are still in the prototype stage, but we hope to be able to put them into production and make them available to everyone in the next few months. The repository created from user data will be enhanced by a nationwide restitution of indicators on the state of French beekeeping, drawn up by ITSAP - Institut de l'abeille - in partnership with regional beekeeping development associations. This data can also be made available to basic research to pave the way for new studies, based on a passive participatory science system. The first step was to gather information on beekeepers' needs. This information was used as the basis for the IT development and the functional choices for the tools.

In the long term, we want to set up a decision-making system, based on AI, capable of learning from the decisions taken by beekeepers in a given context (e.g. feeding in winter) to provide advice based on the most common actions. The expertise of the development structures will also be fed into this decision-making system as part of the process of issuing alerts (for example, a food shortage alert in a given sector based on knowledge of the terrain and climate). An environmental data aggregator will complement the data entry tools available to beekeepers, to give them a better understanding of the characteristics of the sites they use for their apiaries, and to help them make the right choices. The data collected will be fed into a new reference system, created by the profession, in which beekeepers will be able to situate their practices and identify the strengths and weaknesses of their hive management. This reference system will also provide indicators of the state of health of French beekeeping, particularly in terms of winter losses, varroa mite treatment strategies and quantities of honey (or royal jelly) harvested. All the functions implemented in the digital support platform for beekeepers, as well as data re-use rights and the final economic model for this IT system, will be discussed with the beekeepers. Consultation with future users is central to the project in order to guarantee the relevance of the service provided and the consent of users to the re-use of their data.

*** Translation of the French terms:**

Figure 1:

Représentation graphique: Graphical representation
Service d'alertes: Alert service
Tableaux et indicateurs: Dashboards and indicators
Saisie Vocale: Voice input
Sauvegarde des données: Data backup
Partage de données entre apiculteurs: Data sharing between beekeepers
Intégrer les données des balances automatiques: Integrate data from automatic scales
Référenciels: Reference systems
Gestion des produits finis: Finished product management
Gestion des consommables: Consumables management
Gestion comptable: Accounting management
Intérêt (concern):
Très intéressé: Very interested
Intéressé: Interested
Moyennement intéressé: Moderately interested
Pas intéressé: Not interested
Pas d'avis: No opinion

Figure 3:

Ruchers: Apiaries
Date de récolte: Harvest date
Type de miel: Type of honey
Pose de chasse-abeilles: Placement of bee escape boards
Opérateurs: Operators

Figure 4:

Données statiques: Static data
Données de saisies: Input data
Données de planification: Planning data

Figure 5:

Planification: Planning
Gestion de compte: Account management
Emplacements et Ruchers: Locations and apiaries
Saisie des données: Data input

Figure 6:

Emplacements: Locations
Traitements Varroa: Varroa treatments
Gestion des stratégies: Strategy management
Planification des traitements: Treatment planning

Ethics

The authors declare that the experiments were carried out in compliance with the applicable national regulations.

Declaration on the availability of data and models

The data supporting the results presented in this article are available on request from the author of the article.

Declaration on Generative Artificial Intelligence and Artificial Intelligence Assisted Technologies in the Drafting Process.

The authors used artificial intelligence in the translation process from French to English.

Author ORCIDs
Jean-Charles HUET: https://orcid.org/0000-0002-0859-4734
Lamine BOUGUEROUA: https://orcid.org/0000-0002-5322-8231

Authors' contributions
Jean-Charles HUET and Lamine BOUGUEROUA wrote the article as first authors and contributed to the project as digital experts.
Yassine KRIOUILE contributed to the development of the software and the Artificial Intelligence models, as well as acting as a proofreader.

Alexandre DANGLEANT, Axel DECOURTYE and Constance BERI contributed as lead authors and reviewers.
Adèle BIZIEUX, Lucille JOHANNET, Pascal JOURDAN, Coline KOUCHNER, Elodie RUMIANO and Alicia TESTON helped to describe and explain the requirements.

Declaration of interest

The authors declare that they do not work for, advise, own shares in, or receive funds from any organisation that could benefit from this article, and declare no affiliation other than those listed at the beginning of the article.

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