Beyond Sensor Data Analysis: Unexpected Challenges in a Honeybee Monitoring Project

Dániel Tamás Várkonyi, Márta Alexy and Tomáš Horváth

ELTE – Eötvös Loránd University in Budapest, Faculty of Informatics, Department of Data Science and Engineering, Budapest, Hungary

Abstract

With shortage in human workforce and increasing ecological challenges application of Internet of Things and Artificial Intelligence technologies in the agricultural sector, known also as precision farming, has become very popular in recent years. Agriculture is, however, a domain with specific challenges which AI engineers and data scientists usually do not face in other domains, such that healthcare, industry or services, just to name a few. In this paper we collect and summarize the challenges and problems which arose in our honeybee monitoring project from which the most important are trust, seasonality, data labeling issues and sudden events. We believe that, despite not focusing on Machine Learning models nor providing technical details, this paper provides an interesting reading for data scientists and will serve as an aid for planning and executing data science projects in the agricultural domain.

Keywords

Precision Farming, Sensor Data Analytics, Honeybee Monitoring, Data Science

1. Introduction

Beekeeping is a small sector that plays an important role in food industry and agriculture due to honey production and pollination of a wide variety of crops [1, 2]. Unfortunately, honeybee colonies have suffered significant declines in recent years [3] due to various diseases and irresponsible agricultural practices.

The identification of the health condition of a bee colony is done manually, by opening and inspecting the hive, in the majority of apiaries. By opening the hive the beekeeper disturbs the colony and, thus, introduces a certain level of stress to the bees. Moreover, during each manual inspection the micro-climate of the hive temporarily changes, requiring to put additional effort for the bees to re-establish the equilibrium of their hive which, consequently, results in a reduced amount of honey the given bee colony produces.

Hungary belongs to the most important honey producers in EU w.r.t. bee density and honey production (in kg/100 km^2) [4], thus, our project aimed at remote monitoring of bee hives would create an added value to this sector of agriculture. It is important because there is, as usual in the EU, a shortage in manual labour. Moreover, so-called "smart hive" solutions would save considerable manual effort to the aging Hungarian beekeeping community.

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varkonyid@inf.elte.hu (D. T. Várkonyi); abalord02@inf.elte.hu (M. Alexy); tomas.horvath@inf.elte.hu (T. Horváth)

1.1. Our Project

The original goal of our project, based on the request from our project partner, the the Natura mérnökiroda Ltd. (https://naturami.hu/), was to detect swarming activities from audio data recorded in beehives.

The majority of related works on beehive audio analysis is focusing on swarming prediction [5, 6, 7, 8, 9]) which, translated into the terminology of machine learning (ML), corresponds to a binary classification task (i.e. "'the colony is in a swarming state or not"). However, the sound of a bee colony in swarming state is well distinguishable from the case when the colony is not swarming, even for human ears [10, 11]. In the light of the above facts, it is not surprising that many ML techniques achieve good prediction accuracy on these tasks (see, e.g., [12, 13, 14, 15]).

Thus, we have been altering our focus on other problems important in beekeeping, such that the detection of various diseases, just to name one, which correspond to a more complex ML task of multi-class or multi-label classification. In these cases, the beehive sounds corresponding to various classes might not be so easily distinguishable from each other as in the case of the above mentioned task of swarming detection. Another issue, not investigated so far in the literature is that different colonies might react to certain anomalies (disease, intruder, sudden environmental change) in different ways depending on their physical or health conditions.

For such, a natural (research) question would arise, such that, if it is possible to identify a colony by its noise. In other words, if there is some kind of "audio fingerprint" of a colony which would enable us to perform beehive audio data analytics in a personalized manner.

We have developed a noise filtering approach, specifically for beehive audio data, using which very good accuracy in beehive identification can be achieved even with using only very small neural networks [16].

Meantime, besides the microphones, we have installed other types of sensors, such as temperature, humidity, scale and video into the beehives at our test site. The data are being gathered continuously and implementations of baseline approaches for multi-modal data analytics [17] are being implemented. Our recent research consists of analysing these data in order to develop novel approaches for beehive monitoring.

The permanent research team consists of two authors of this paper, the authors D. T. Várkonyi and T. Horváth, with master students working under their supervision. The data collection, in co-operation with our project partner (Natura mérnökiroda Ltd.) has started in Spring 2020. Later, at the end of the same year, the apiary in which we have been collecting the data had to be liquidated, thus, in the Spring 2021 we have installed the sensors in an other apiary.

1.2. Motivation for this Paper

During the course of our project on remote monitoring of beehives, several challenges have popped up which are specific for the beekeeping domain but one can expect the majority of them appearing in other areas of agriculture as well. Even if we assumed that there would be some issues slowing down our work we did not count with these challenges to have such a considerable impact on our project.

It is important to mention that our project is pursued within the academic (i.e. public) and agricultural sectors in an Eastern-European country with its specific operational constraints (e.g. public procurement) which might not be so crucial in the private sector.

The main idea behind this paper is to summarize the challenges we had/have to deal with in our project, providing the community with a kind of a guide (i.e. "what to expect") when planning or starting a data science (DS) or artificial intelligence (AI) related project in apiculture or agricultural domains, in general. It is important to stress out that various challenges related to the computer science side of our project, such as hardware and its installation or the complexity of beehive data analytics, have been summarized and described in [18, 19]. While our approach to technical issues expected within the project was based on the knowledge gained from [19], we have met other issues which are equally important but not yet summarized, according to our best knowledge. Here we will devote a separate section to each of the identified challenges where we will also describe our approach as well as its outcome(s).

Thus, this paper does not contain any technical descriptions of the used models nor formal definitions of the data analytics problems we have been dealing with. However, despite that it is not a technical paper, we believe that we can provide an interesting and useful reading to the audience of the conference and, also, to the data science community, in general.

2. Mutual Understanding and Trust

First, we have contacted the Hungarian Association of Beekeepers[1] (HAoB) in order to establish a cooperation and map beekeepers' requirements for the concept of a so-called *smart hive* (SH).

Since each member of the management of HAoB is a practicing beekeeper, mostly with medium sized apiaries (up to a few hundreds of beehives), these sessions were very fruitful and we gained insights into their most important problems (e.g. diseases, irresponsible farming practices of crop farmers, changing ecological conditions, bureaucracy and reporting obligations to the authorities, lack of man power, etc.) as well as their main work processes and working conditions.

On the other hand, beekeepers showed interest in possibilities of supporting their production using AI and DS techniques, however, we have found out that their expectations, based mostly on movies and popular science, were quite unrealistic from our point of view.

Probably arising from the above mentioned distorted expectations, we have noticed that those beekeepers who had come into contact with some of the existing SH solutions have felt a relatively strong mistrust towards our project. This was originating from the fact that the market is flooded with various SH solutions which are quite costly[2] and, according to these beekeepers, do not work properly[3]. The usual concern raised by beekeepers regarding our initiative was that they have payed hundreds of Euros already for various products, however, they "were useless for them" and what would be the guarantee that our solution would work better.

For such, we realized that the community of beekeepers, as well as farmers in general, have their "regional influencers" which play an important role in the process of acceptance of new technologies. As it turned out, it is a well-known fact amongst dealers and sellers of agricultural technologies and products, however, we have been not aware of it. Also, the farming community is

[1] http://www.omme.hu/ (only in Hungarian)

[2] We have checked the available solutions and could confirm that they are relatively expensive for Hungarian (or Eastern-European) beekeepers.

[3] For budgetary reasons, we did not tested these solutions. Also, since the related websites and documentations to these products do not uncover enough technical details (e.g. which techniques of AI they utilize, how were they trained, etc.), we are not able to judge these products from the AI or DS point if view.

more old-fashioned implying that the acceptance of new technologies is more cumbersome than in case of other application domains we have worked in (e.g. healthcare, manufacturing, telecommunication or services).

To sum up, the following two crucial issues, which were impeding the progress in the initial phase of the work, have been identified within our project:

Lack of background knowledge Farmers and computer scientists had only some very basic and shallow ideas about the other domain[4]. To address this challenge, from our side, we have been studying introductory literature on beekeeping and research papers in the apiculture domain. Tomáš Horváth, the second author of this paper, has absolved an education training on beekeeping (with the duration of approximately 300 hours). This not only helped us to gain more insights into the area of apiculture, working processes and everyday problems of beekeepers but also changed the attitude of beekeepers[5].

Motivations and Expectations Being researchers in an academic environment, we were expecting to focus in the project on research problems solving which would lead to scientific publications. On the contrary, naturally, beekeepers expected simple solutions supporting their decisions and alleviating their manual work. We have expected that visualizing the gathered sensor data would be enough, however, the majority of beekeepers was not interested in "looking at the data" (i.e. time-series) but rather they would like to have predictions on future events and their possible outcomes based on the current status of their hives. For such, however, we would need lots of feedback and context information provided by the beekeepers, a requirement which is almost impossible to fulfill from beekeepers' side due to their work overload[6]. We are still seeking for the best way of gathering these information from the beekeepers (e.g. implementing some gaming principles into the application). We also spent considerable time with discussing our (way of) work to the farmers stressing out its usually lengthy time span[7].

On the other hand, compared to other domains such that healthcare, finance or telecommunication, just to name a few, we have been pleasantly surprised regarding the following matter of fact:

Verbal agreement During the whole project we have not run into the issues of legal contracts, non-disclosure agreements or data protection regulations (e.g. GDPR) which are common in other application domains and, thus, we have been expecting some delay in getting the data or some degree of control over our publishing activities. The beekeepers, we think that due to their way of cooperation with other beekeepers and farmers (e.g. who cultivate the flowering crops), were relying on a "gentleman's agreement" and all of them were keeping their word. On the other hand, they were/are expecting to keep our side of these agreements as well.

3. Hardware

There are several issues regarding the hardware which are important when planning or conducting this kind of project. Almost all of these have been covered in [19], however, mainly from the point of view of technical execution, adequacy of current solutions as well as perspectives for future development. It is also worth noticing that the majority of related work in precision beekeeping are either commercial solutions providing a generic data collection and analytics platform or scientific papers focusing on certain aspects of beekeeping. However, in the former case, commercial solutions usually do not consider the differences in beekeeping practices related to various subspecies of honeybees or regional as well as geographical conditions, as would be optimal and is also stated in [19].

To sum up, the following challenges related to hardware are the most crucial in our project:

The price-value trade-off It would be optimal to have all the hardware installed in each hive, however, there are some financial limits Hungarian beekeepers are willing to accept[8]. On the other hand, various equipments are in different price ranges. For example, a weighting scale, quite important for measuring the honey yield, is more expensive than a temperature sensor. We have to experiment with several types of sensors since the sensitivity and precision of these were oscillating on a rather wide range and, thus, it took time to find the precise and affordable equipment for our project. Keeping this in mind, we recommend to acquire more types/brands from the same sensor to not waste time in case a specific type would not work reliably.

[4]We have also met hobby beekeepers working as IT engineers in their everyday job, however, this is rather an exception.

[5]One of the instructors of the beekeeping course allowed us to use his apiary as test site for the project.

[6]It is important to note that for the majority of beekeepers in Hungary, even with around a hundred beehives in their apiary, beekeeping is still a supplementary occupation besides their regular jobs.

[7]For example, the main beekeeping season, i.e. flowering of the main crops, lasts usually for about 3-4 months while this time is not enough for developing and testing the prototype nor an in-depth research.

[8]The decision on how much beekeepers are willing to pay for a SH solution is also influenced by the season. If the season is very bad, as was the year 2021, this sum is very low or even zero.

Figure 1: The main types of beehives (from left to right): vertical (known also as "Langstroth", modular and flexible, the most used type in high production apiaries), horizontal (traditional Hungarian type, still popular), top-bar and "Warre" hive. The latter two type of hives are used in natural beekeeping. Images were taken from http://www.kaptaruzem.hu/ and https://beebuilt.com/.

Public procurement vs. Seasonality Being a public institution, all hardware acquisition is required to be made through public procurement which, usually, takes time. It is an especially important issue due to the seasonality of beekeeping where the hives shouldn't be opened below 16 °C and, thus, the hardware can not be installed during the whole year. For such, we have decided to buy the cheap equipment, the sensors, from our personal budget. While the more expensive hardware, e.g. the 4G router with the pre-payed SIM card, acquired through public procurement have arrived[9] we have been installing and testing the sensors in laboratory conditions and, after, used our own 4G router when these sensors have been installed at the apiary.

Positioning and Ergonomy There are many types of beehives, as illustrated in Figure 1, each of which have their specifics and, thus, influences the way sensors should be placed within them. Moreover, various parts within the beehive are utilized by the bees for various purposes such that, for example, honey and pollen storage, queen's nest and drone hatchery. Also, it is natural that bees are regulating the temperature and the humidity within the hive, concentrating more to the part where the queen and its nest is located. As a result, it might happen that there are different conditions in different parts of the beehive (e.g. more humid and warm near the entrance in a hot or rainy day, respectively). Moreover, during the winter period, the queen's nest, forming a ball shape the outer temperature of which is different from its inner temperature, is moving slowly towards the remaining storage of honey, usually, drawing away from the entrance of the hive. Thus, it is important that sensors are located in the right places of the beehive. Regarding this, we, together with our beekeeper partner, are still working on the question of positioning the sensors within the beehive. An other important issue is paying attention on the work ergonomics during beekeeping. Sensors shouldn't be in the way when the beekeeper is extracting the frames for inspection nor the installations outside the beehive (see [20], for example) should cause any accidents such that, e.g., falling over on cables or cumbersome removal of the parts of the beehive due to outer parts of the hardware being in the way. It is extremely important when the SH solution is being installed in a "non-hobby" apiary when the effectiveness of the production is essential.

Beekeeping-specific circumstances When planning a precision farming project one should keep in mind some "farm-specific" conditions which might influence the technical infrastructure. For example, weather conditions (humidity, hot, cold) might cause the hardware to break down or go off, domestic or wild animals within the apiary can damage the equipments and, especially in the case of nomadic beekeeping, it might happen that the connection to electricity or internet is insufficient. Another issue mentioned in [21], specific to beekeeping, is that bees have the tendency to cover foreign objects inside the hive with propolis (bee glue) and/or seal wholes with beeswax which might influence or distort sensor measurements. To avoid this, placing sensors in queen expedition cages, as proposed and done in [21], or some custom-made covers, as can be seen in the Figure 3, is desirable.

[9]This took about one year, including the winter season.

Figure 2: Installation of our hardware in the beehives at the Farkas méhészet apiary in Biatorbágy, Hungary. The waterproof boxes, containing a camera and a Raspberry PI, were bought at the electric hardware store. They are located in the front of the hive due to the camera capturing of the entrance and, also, due to ergonomics reasons (the beekeeper used to inspect the hives from behind, thus, the boxes are not in the way). The central unit containing a 4G WiFi router is located in a plastic box below the middle hive to which the sensors are connected by wires, the data processing unit is connected by WiFi. (We expect the sensors to break down in 2–3 years due to the conditions they are located in such that UV radiation, heat, frost, etc.)

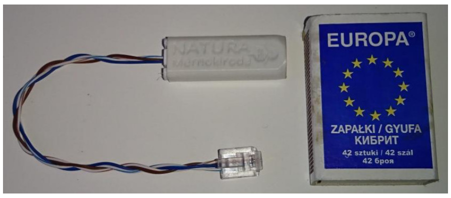

Figure 3: Audio sensor used in our project and its protection made on a 3D printer, both developed and manufactured by our project partner, the Natura mérnökiroda Ltd. A box of matches on the right is for showing the size of the hardware.

4. Information Besides the Sensor Data

We are collecting large amount of data from each beehive (see Figure 2, such that temperature and humidity readings, video as well as audio recordings, from which, so far, we have been focusing mainly on the audio data. The benchmark data we are using consists of 10.000 audio files of length of 8 seconds, recorded from 10 beehives. However, the data are not labeled (yet) due to the following: During the beekeeping season the farmers are too busy with their everyday work in the apiary. However, after the season is over and they would have more free time, it is a quite cumbersome job to label historical data, especially, of a large quantity of recordings[10].

Another information which could be beneficial for deeper data analytics is the production data, such that, the yields and quality of honey from various crops, the history of sanitary and medical treatments of the bees (including the types and dosages of the used substances and agents), the history of feeding[11] (indicating the type and amount of nutrition), etc. However, even in larger apiaries, these data are either logged in a paper notebook or not logged at all. Our project partner, the Naturami mérnökiroda Ltd. is currently developing an application for "user-friendly" gathering of such data helping the beekeepers to keep track of inspections in their apiaries, thus, in the future, we will have access to these types of data as well.

5. Sudden Events

Since the project is not conducted indoors, weather conditions at the apiary might cause sudden changes in the plans. First, not considering urban beekeeping, apiaries are not located in the city where our university workplace is[12]. Thus, it might happen and also happened to us a few times that shortly after our team arrived in the apiary, raining or wind started and the planned work had to be re-scheduled.

Weather, but also other unforeseen events (e.g. noisy machines working or chemical spraying in the close neighborhood of the apiary) might cause the bees to be very aggressive which makes the work impossible. We usually receive some bites during our work. However, when in case of aggressive bees, someone can receive multiple bites which might lead allergic reactions (even if a person has no severe allergy to bee bites as happened with the member of our team).

Finally, there are various diseases which one planning a SH project should plan with. First, when working with multiple apiaries, one has to take care to not spread a disease from one apiary to the other. When we enter an apiary, we use the protective clothes which the beekeeper gives us[13]. Second, the equipment should not be carried over from one apiary to the other, unless it is properly sanitized. In case of some serious honeybee diseases, such that the American foulbrood[14] (Pestis americana larvae

[10] Here, some strategies from the area of active learning [22, 23] can be utilized, however, it would need a proper user interface.

[11] Beekeepers used to help to maintain the colonies' conditions by feeding them using various types of nutrients (mainly sugar and some vitamins).

[12] To reach our test site apiary, located 30 kilometres from our workplace, we usually drive about half an hour by car, depending on the traffic.

[13] Beekeepers usually have a few additional protective clothes which are not in use besides their apiary.

[14] This disease is not rare in Hungary, nor in the EU, causing lots of harm to beekeepers. One of our beekeeper partner, at the beginning

apium), the hives with all of their accessories should be burned due to spores of the disease that remain viable for up to decades (see Figure 4). Only those equipments can be kept which are able to withstand the flames (e.g. metal tools), which is not the case of the used sensors. Thus, one might count with this possibility as well (including how to handle such case in the inventory of the university) and have some backup hardware acquired.

Figure 4: Burning all the hives in an apiary after getting infected with American foulbrood (source:Wikipedia).

6. Conclusions

In this paper we were introducing and summarizing the problems and challenges we were/are facing in our project related to beehive analytics in smart hive solutions.

We did not provide any technical details from our research [16] but, rather, were focusing on technical and organizational issues which have delayed our work on the project even if we did not assume them to be so crucial or did not expect them at all. These problems and challenges can be grouped into four groups such that i) mutual understanding and trust between computer scientists and farmers, ii) hardware related issues, iii) lack of information besides the sensor data and iv) sudden events. Where possible we were indicating how did we approach these challenges.

We believe that this work will be useful for computer and data scientists in planning and carrying out their projects related to precision beekeeping or precision farming, in general.

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of our project, has lost his whole apiary consisting of few hundred beehives.

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