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Model for the bee apiary location evaluation

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Abstract. Honeybees are predominant and ecologically as well as economically important group of pollinators in most geographical regions. As a result of analysing current situation in studies and practices, a conclusion was drawn that beekeeping sector is in decline. The identified reasons for this are land-use intensification, monocropping, pesticide poisoning, colony diseases, parasites and adverse climate. One of the solutions is to find a proper bee colony harvesting location and use luring methods to attract bees to this location. Usually beekeepers choose the apiary location based on their own previous experience and sometimes the position is not optimal for the bees. This can be explained by different flowering periods, variation of resources at the known fields, as well as other factors. This research presents a model for evaluation of possible apiary locations, taking into account resource availability estimation in different surrounding agricultural fields. Authors propose a model for real agricultural field location digitization and evaluation of possible apiary location by fusing information about available field resources. To achieve this, several steps have to be completed, such as selection of fields of interest, converting selection to polygons for further calculations, defining the potential values and coefficients for amount of resources depending on type of crops and season and calculation of harvesting locations. As the outcome of the model, heat map of possible apiary locations are presented to the end-user (beekeeper) in the visual way. Based on the outcome, beekeepers can plan the optimal placement of the apiary and change it in the case of need. The Python language was used for the model development. Model can be extended to use additional factors and values to increase the precision for field resource evaluation. In addition, input from users (farmers, agricultural specialists, etc.) about external factors, that can affect the apiary location can be taken into account. This work is conducted within the Horizon 2020 FET project HIVEOPOLIS (Nr.824069 – Futuristic beehives for a smart metropolis).

Key words: precision beekeeping, smart apiary location, harvesting location evaluation, HIVEOPOLIS.

INTRODUCTION

Pollination is an essential ecosystem service, and bees are critical to the rich diversity of fruits, vegetables, and nuts humans eat (Bolshakova & Niño, 2018). Bees help to preserve wild biodiversity for 90% of crop species, and sustain the health and vitality of human food production and pollinators are required for producing of 15 to

30% of the human food supply (Greenleaf & Kremen, 2006). The value of the European honey bee, *Apis mellifera L.* to pollination services is estimated at $217 billion globally and $20 billion in the United States annually (Frankie et al., 2014). For the last decade, annual bee and hive losses have considerably increased. Declines in pollinator populations could have serious economic repercussions, including rising food costs and potential crop failures (Potts et al., 2016). Without the bee pollination, many of our favourite healthy foods, such as almonds, avocados, apples, watermelons, would be at risk. The loss of honeybees would also affect the meat and dairy industries as many of the crops requiring bee pollination serve as food for animals. Without honeybees, farmers would have to use other, more expensive, but less effective pollination techniques and consumers would pay the price. Thanks to the progress in information and communication technologies, new tools and services are available worldwide to manage and constantly monitor the bee colonies (Komasilovs et al., 2019). Precision apiculture (called also Precision Beekeeping) is developed and is defined as an apiary management strategy based on the monitoring of individual bee colonies to minimize resource consumption and maximize the productivity of bees (Zacepins et al., 2015). Idea of the Precision Apiculture is to monitor the main bee colony parameters in real life and make on-time decisions. One of the important managemental decisions for the beekeeper is to select the best placement location for apiary. Optimal location will allow bee colonies to forage on higher amount of the resources with minimal energy consumption. As it is stated by (Vlad et al., 2012) to ensure maximum productivity and continuous honey gathering, beekeepers move their beehives closer to the honey resources. It can be almost considered as a requirement in order to stay competitive in the honey market and to ensure sustainability. The importance of the appropriate site selection, taking into account the range the bees can fly and the food sources available, is also emphasized in (Poelsma, 2019). There is also a web tool ('Honey bee forage map') available (https://www.beepods.com/honey-bee-forage-map/), that allows one to observe the nearest locations (area) the bees can visit within a specific radius (e.g., 2 km or more), however this tool does not provide any information about possible food sources and optimal placement for beehives.

Apiary location selection is usually based on beekeepers' previous experience, according to the flowering calendar of different crops and plants, or the limited availability of physical space. Beekeepers can also be informed by the local farmers who need the pollination service. Unfortunately, apiary location does not guarantee that bees will fly to the field wanted by beekeeper, therefore it is required to guide bees to designated place for optimal resource harvesting. There are several methods for manual bee colony attraction to specific location (field). One of the methods is to place sugar syrup at the field to attract bees, resulting in bees' memory pattern development, which in return ensures that bees will prioritize this particular field for their next gather trips. However, this technique is prohibited in some countries. There is also an idea of directing bees to nearby acacia trees by placing acacia flowers at the hive entrance; however, this beekeepers' idea has not been scientifically confirmed.

Sometimes beekeepers want to harvest honey from specific places, pursuing single-source honey – e.g. linden bloom or spruce honeydew – to obtain honey with distinct flavour, as such honey is more valuable on the market (Crane & Walker, 1985; Persano Oddo et al., 2004).

In some countries, for example in Indonesia (Gratzer et al., 2019), migratory beekeeping is very common, and beekeepers are forced to change the apiary location often to provide food sources for their bees. By utilizing semi-automated decision support system for identifying optimal apiary location, beekeepers could be able to decrease the expenses and effort related to migrating the bee colonies. In addition, it could result in increase of the potential amount of forage resources. The optimal number of bee colonies placed in a particular location or region is also questionable, as it introduces in-between colony resource distribution challenges and competition. For example, natural colony density as determined for both Palearctic and Nearctic forests was established at 0.5 colonies per km^2 (Galton, 1971; Visscher & Seeley, 1982). Other studies show the numbers of natural density of 0.11–0.14 honey bee colonies km^{-2} (Oleksa, Gawroński & Tofilski, 2013; Kohl & Rutschmann, 2018).

In the future, with increase of automation and robotics, implementation of such solutions to the beekeeping sector may result in possibility to automatically direct bees to a specific location. There are already researches and prototypes addressing this objective (Landgraf et al., 2018). This technology would allow guiding the bees to location beekeepers consider to be optimal, and pollinate only the necessary fields, excluding potentially dangerous for the bees (containing pesticides), unwanted fields and limiting risk factors linked to flying paths of the bees. Therefore, it will be necessary to gather information about the available resources in the fields, possible dangerous places, potential flying paths, etc.

The aim of this research is to develop a model, which can be afterwards integrated in a wider platform, which potentially will provide support for beekeepers in finding and selecting good apiary locations, and in future, could also be integrated into a system of futuristic hives with the aim to autonomously find the best harvesting location. Proposed model for the bee apiary location evaluation is the first stage of the complex data fusion solution for beekeeping needs, which would be developed and built in the future.

This research is conducted within the Horizon 2020 FET programme project HIVEOPOLIS (https://www.hiveopolis.eu/). Collection of hives, technologies and humans is called Hiveopolis in our concept. HIVEOPOLIS technology will be integrated in a way that it provides a synergistic added value to the colony, to its owner and to the society in general.

DEVELOPMENT OF THE MODEL FOR BEE APIARY LOCATION EVALUATION

This section presents a model for evaluation and selection of possible apiary locations utilizing aerial and satellite images of agricultural fields. The model development process can be divided into two main steps. In the first step, the fields in the aerial image of the region are annotated with a polygons and an estimated value of resources on that field. As the result, authors obtain a semantically annotated map, which can be used for automatic evaluation. Based on this semantic map, in the second step, the method calculates a value function assigning each location on the map an estimated amount of resources to be collected at that location. This value function is then used to estimate favourable apiary locations as local maximums. Model is developed in Python language using several libraries, including Matplotlib (Hunter, 2007), NumPy (van der

Walt, Colbert and Varoquaux, 2011), Shapely (Gillies, 2007) Python package for computational geometry.

Further, the method is discussed and illustrated in more detail. To develop the proposed model several steps have to be completed:

1. Get the region of interest from the map

- At this point the system is intended to be used by a beekeeper. User (beekeeper) should choose the needed image and crop the region of interest to work with (see Fig. 1). Authors used Google Maps for selection of images of terrains and regions. Used part of the map can be seen here: https://www.google.com/maps/@56.5696785,23.4593229,5558m/data=!3m1!1e3. It is assumed, that dimension of the region of interest is 10 km to 10 km. Region of interest can be also different if needed.

$W = 10{,}000$

where W – map region width (m).

Figure 1. Example of terrain map used for model evaluation.

Figure 2. Example of some defined polygons on the map.

2. Define polygons which are representing agricultural fields or possible sources of resources for bees

- At this moment, this task is completed manually using specifically developed basic web interface. User should mark all the vertices (see Fig. 2 for demonstration of some defined polygons) of each polygon and the tool will extract their coordinates.
- In the example, there are 56 polygons defined within selected region.

$$\forall f_n \in F \rightarrow p_n = O(f_n) \quad (1)$$

where F – fields from regions of interest; *O(f)* – polygon outlining the field.

3. Transfer real image to semantically annotated map of polygons

- Based on the coordinates generated from previous stage, the map annotated with chosen polygons is built (see Fig. 3 and Fig. 4). This map can be further processed in many different ways, applying different parameters for the polygons and implementing other layers (for example roads).

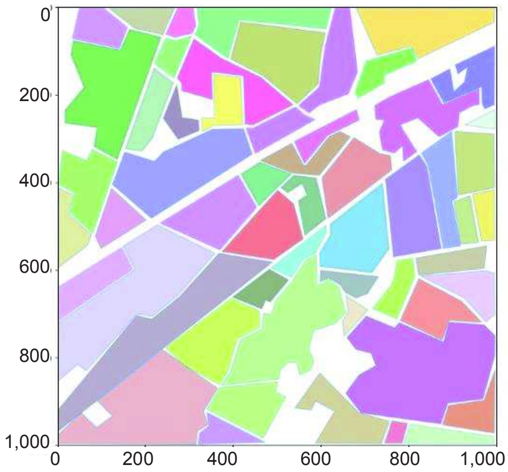

Figure 3. Generated digitized map of marked fields and regions.

Figure 4. Digital map combined with the real map.

4. Define each polygon value

- One of the options for processing the polygons is to define field values and assign them to already generated polygons. Practically, field values should be related to the theoretical amount of resources available for bee forage. It is a very challenging task to evaluate the exact amount of resources available at a foraging location. It is possible to use the information about specific plants and crops and their indices describing pollen and/or nectar production. In the provided example, polygons' values are assigned randomly to demonstrate the calculation method itself, therefore values can be different from the real situation. It is assumed that five different agricultural plants are growing in the selected region. The field nectar production is from 20 kg to 100 kg from one hectare.

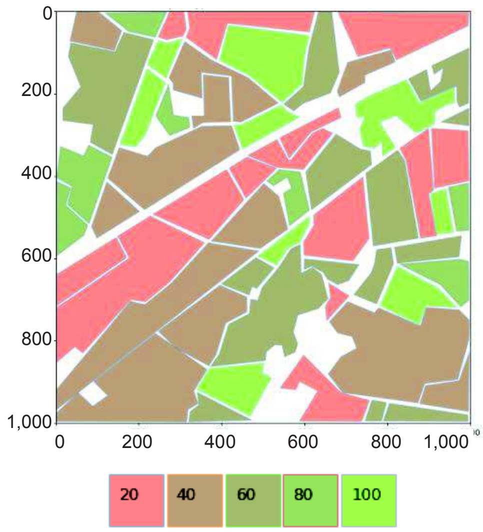

Figure 5. Encoding of the fields.

$$v_n = V(p_n) = R \in \{20,40,60,80,100\} \quad (2)$$

where *V(p)* – plant honey production index in a given field (represented by polygon)
R – uniform random distribution over a set of values.

- To visually differentiate the fields by their value, colour encoding is implemented, ranging from bright red to bright green, with five colour steps. The region with the highest value will have its polygon coloured bright green (see Fig. 5).

5. **Calculate all possible positions of the bee apiary**

• Within this stage all possible apiary locations are considered, calculated and evaluated. This is completed by going through the annotated map in a sliding window mode and multiplying the area of polygons (fields), which is within the possible bee colony flying region, with polygon value. Flying distance of the bee colony is considered within the radius of 3 km from the colony location (Prešern, Mihelič & Kobal, 2019). Another source states that productive flying radius of the bee colony should not exceed 2 km (Кривцов and Лебедев, 2019). This parameter can be adjusted by the user if needed. In the authors' case, the radius of 3 km is chosen. Authors assume the harvesting region of the bee colony to be a circular region around the apiary location. Authors also assume that each point within the harvesting region is equally likely to be reached by the bees. In order to estimate the value of a given location, the values of all field polygons that intersect with the harvesting region are integrated and weighted with the area of intersection.

$$C(x_c, y_c) = \{(x, y): (x - x_c)^2 + (y - y_c)^2 \leq r^2\} \quad (3)$$

where C – harvesting area of a colony (circle) placed at (x_c, y_c) coordinates; r – harvesting distance (r = 3,000 in the example).

• Other parameters used in the model are:

✓ 2.5 kg of foraged nectar is required for a colony to produce a 1 kg of honey (Гребенников, 2005).

✓ Honeybees are foraging only approximately 35% of maximal possible field nectar (Нарчук and Морева, 2016).

$$\forall x, y \in \{1..W\} \rightarrow H(x, y) = hk \sum_n V(p_n) * C(x, y) \cap p_n \vee \quad (4)$$

where $H(x, y)$ – total potential harvest for single colony placed at (x, y); k – honeybees foraging efficiency (k = 0.35 used in example); h – nectar to honey production rate (h = 0.4 used in example.

6. **Visualise resource availability using the heatmap**

• For better demonstration of the calculation outcome the field resource availability heat map is generated and shown to the user (see Fig. 6). Resource availability is calculated for each possible apiary location.

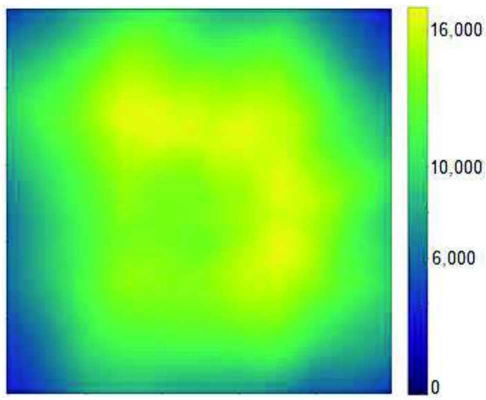

Figure 6. Heat map of resource availability in each possible point.

7. **Choose the best place for the apiary location**

• Based on the value function, the system generates a heat map and proposes the best possible apiary locations.

• In addition, several parameters were considered:

✓ One bee colony consumes up to 90 kg of honey for their local needs (Лебедев and Кривцов, 2019);

- ✓ Maximum number of bee colonies in one location is equal to 70;
- ✓ Minimum number of bee colonies in one location is equal to 15;
- ✓ Average amount of honey production per colony is equal to 60 kg.

$$argmax_{x,y} H(x,y)$$

subject to

$$H(x,y) \geq H_{colony}$$
$$15 \leq N(x,y) \leq 70$$

where H_{colony} – amount of honey needed for the colony survival; $N(x,y)$ – number of colonies placed at a location (x, y).

Based on this parameters the model calculates the best possible apiary locations and demonstrates the apiary location to the end user, where the number represents the maximum hive count in the one apiary. In this particular example, there are three locations where maximum number of colonies is possible (number 70) and five additional locations with less number (less than 70) of colonies (see Fig. 7).

Figure 7. Demonstration of optimal apiary locations.

When the apiary location is chosen, it is needed to check if the location is viable, e.g. it is not on the road or at some restricted place (like field is a private property, and it is not allowed to enter and place bee colonies, etc.). At this point, this stage is not automatized, but is planned to be improved in the future.

PLANNED FUTURE IMPROVEMENTS OF THE MODEL

In the future work, it is planned to automate some model development stages, like definition of polygons, which could be time consuming task in case there are many fields to describe in a chosen image. Potentially, the machine learning techniques can be applied to solve this task.

In the future, the model presented in the previous section will be integrated in a more general system. Authors propose to develop augmented map to show potential places for bee colony nectar/pollen foraging with some useful additional attributes, like amount of food resources, the quality of the food base, some additional data (for example the name of a crop or plant growing on the field). Information to be used by augmented map can come from different data sources already available or generated in the future.

One of the main data sources should be supplied by the farmers, regarding flowering of the field, and/or usage of substances (chemicals, pesticides) that can potentially harm the bees.

In the future, the output of the augmented map can be autonomously taken by the futuristic bee hives for planning a nectar collection.

CONCLUSIONS

Authors propose a model that can be used by beekeepers to choose the optimal place for apiary location and to plan transportation of hives, when potential resources of one field will come to an end.

The model is implemented in Python language and could be improved in the future by adding additional parameters for polygons to better describe the real-life situation.

The model development is in its early stage and requires further development and evaluation in real world conditions.

With the implementation of Precision Beekeeping and autonomous beekeeping, futuristic bee colonies could be able to use the information provided by the model by themselves to plan the foraging location and its intensity.

In this work, the model for an apiary location evaluation is developed for use by potential users, but in the future, it is planned to build up an interface to provide the evaluation not for human user but for machine or for augmented organism, like futuristic beehives.

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REFERENCES

Bolshakova, V.L. & Niño, E.L. 2018. *Bees in the Neighborhood: Best Practices for Urban Beekeepers*, *Bees in the Neighborhood: Best Practices for Urban Beekeepers*. doi: 10.3733/ucanr.8596.

Crane, E. & Walker, P. 1985. 'Important honeydew sources and their honeys', *Bee World*, 66(3), pp. 105–112. doi: 10.1080/0005772X.1985.11098832

Frankie, G.W., Thorp, R.W., Coville, R.E. & Ertter, B. 2014. *California Bees and Blooms: A Guide for Gardeners and Naturalists*. Heyday. 320 pp.

Galton, D. 1971. *Survey of a thousand years of beekeeping in Russia*. Bee Research Association, London.
Gillies, S. 2007. 'Shapely: manipulation and analysis of geometric objects'. Available at: https://github.com/Toblerity/Shapely.
Gratzer, K., Susilo, F., Purnomo, D., Fiedler, S. & Brodschneider, R. 2019. 'Challenges for Beekeeping in Indonesia with Autochthonous and Introduced Bees', *Bee World* **96**(2), pp. 40–44. doi: 10.1080/0005772X.2019.1571211
Greenleaf, S.S. & Kremen, C. 2006. 'Wild bees enhance honey bees' pollination of hybrid sunflower', *Proceedings of the National Academy of Sciences of the United States of America* **103**(37), pp. 13890–13895. doi: 10.1073/pnas.0600929103
Hunter, J.D. 2007. 'Matplotlib: A 2D Graphics Environment', *Computing in Science & Engineering* **9**(3), pp. 90–95. doi: 10.1109/MCSE.2007.55
Kohl, P.L. & Rutschmann, B. 2018. 'The neglected bee trees: European beech forests as a home for feral honey bee colonies', *Peer J*, 2018(4). doi: 10.7717/peerj.4602
Komasilovs, V., Zacepins, A., Kviesis, A., Fiedler, S. & Kirchner, S. 2019. 'Modular sensory hardware and data processing solution for implementation of the precision beekeeping', *Agronomy Research* **17**(2), pp. 509–517. doi: 10.15159/AR.19.038
Landgraf, T., Bierbach, D., Kirbach, A., Cusing, R., Oertel, M., Lehmann, K., Greggers, U., Menzel, R. & Rojas, R. 2018. 'Dancing Honey bee Robot Elicits Dance-Following and Recruits Foragers'. Available at: http://arxiv.org/abs/1803.07126
Oleksa, A., Gawroński, R. & Tofilski, A. 2013. 'Rural avenues as a refuge for feral honey bee population', *Journal of Insect Conservation* **17**(3), pp. 465–472. doi: 10.1007/s10841-012-9528-6
Persano Oddo, L., Piana, L., Bogdanov, S., Bentabol, A., Gotsiou, P., Kerkvliet, J., … & von der Ohe, K. 2004. 'Botanical species giving unifloral honey in Europe', *Apidologie* **35**(Suppl. 1), pp. S82–S93. doi: 10.1051/apido:2004045
Poelsma, F. 2019. *Choosing the best location for your beehives*. Available at: https://www.vatorex.ch/en/choosing-the-best-location-for-your-beehives-part-1/.
Potts, S.G., Imperatriz-Fonseca, V., Ngo, H.T., Aizen, M.A., Biesmeijer, J.C., Breeze, T.D., … & Vanbergen, A.J. 2016. 'Safeguarding pollinators and their values to human well-being', *Nature* **540**(7632), pp. 220–229. doi: 10.1038/nature20588
Prešern, J., Mihelič, J. & Kobal, M. 2019. 'Growing stock of nectar- and honeydew-producing tree species determines the beekeepers' profit', *Forest Ecology and Management* **448**, pp. 490–498. doi: 10.1016/j.foreco.2019.06.031
Visscher, P.K. & Seeley, T D. 1982. 'Foraging strategy of honeybee colonies in a temperate deciduous forest.', *Ecology* **63**(6), pp. 1790–1801. doi: 10.2307/1940121
Vlad, V., Ion, N., Cojocaru, G., Ion, V. & Lorent, A. 2012. 'Model and support system prototype for scheduling the beehive emplacement to agricultural and forest mellferous resources', *Scientific Papers A. Agronomy*, LV–2012, pp. 410–415.
van der Walt, S., Colbert, S.C. & Varoquaux, G. 2011. 'The NumPy Array: A Structure for Efficient Numerical Computation', *Computing in Science & Engineering* **13**(2), pp. 22–30. doi: 10.1109/MCSE.2011.37
Zacepins, A., Brusbardis, V., Meitalovs, J. & Stalidzans, E. 2015. 'Challenges in the development of Precision Beekeeping', *Biosystems Engineering* **130**, pp. 60–71. doi: 10.1016/j.biosystemseng.2014.12.001.
Гребенников, Е.А. 2005. *Все о меде*. Минск: Книжный Дом.
Кривцов, Н. И. & Лебедев, В. И. 2019. *Технологии содержания пчелиных семей.* Юрайт.
Лебедев, В.& Кривцов, Н. 2019. *Beekeeping: bee colony breeding and keeping (Пчеловодство: разведение и содержание пчелиных семей). Litres.* (in Russian).
Нарчук, Э.П. & Морева, Л.Я. 2016. 'Nectar as a renewable natural resource', *Biosfera* **8**(3), pp. 301–314.