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Geolocating Bees by Translating the Waggle Dance Into Spatial Coordinates

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Abstract. Bees can communicate the location of interesting resources to forage to their nestmates by performing what we call a waggle dance. Being able to precisely decode the information conveyed with waggle dances would help biologists, ecologists, beekeepers, and even decision-makers to limit the current decline of bees. The challenge addressed in this paper is to find the best way to model in a spatial database the directions given by the waggle dance, and the best way to visualize them. We propose first a method to collect the direction information in a video from an observation hive. Then, we propose three methods to model the uncertain locations indicated by the waggle dance, using a kind of box-plot geometry, clustering and heatmaps. An experiment to find the resources from our maps on the field shows that the heatmap representation is the most promising.

Keywords. honey bees, waggle dance, geolocation, spatial accuracy, geovisualization, cartography

1 Introduction

As far as we know, only humans and bees can communicate information about distant places (Tautz, 2022). The European honeybee (*Apis mellifera*) developed a complex system of dances to communicate about distant places with fellow bees (Von Frisch, 1965). This waggle dance acts as a recruitment interaction, to convince nestmates to forage the same pollen or nectar resource, by also assessing the quality of the resource (Seeley, 1986). Studying waggle dance can be key to solving the current seasonal foraging challenges faced nowadays by honeybees due to climate change and agriculture (Couvillon et al., 2014). Monitoring the foraging areas by decoding the waggle dance can also be useful to precisely identify the floral species inside the foraging area and better characterise the hive products (Galopin et al., 2023). More generally, geolocating the resources visited by honeybees can help biologists better understand their behaviour and interactions with their environment.

As geographic information scientists, the practice tells us to put the decoded dance information into a GIS to monitor the foraging areas. But, until now, geographical information science has been rarely used by scientists studying bees, as even using GIS software is unusual in bee studies (Rogers and Staub, 2013), and mainly restricted to the production of landcover maps with the location of the hives as an additional layer. However, the Beescape project (Robinson et al., 2021) shows how bee scientists, beekeepers, or decision-makers can leverage the potential of geographic information science and cartography to better understand how bees forage their environment.

More concretely, our research is interested in the use of geographic information science to geolocate the information decoded from the waggle dance. When this information is geolocated, we are interested in methods to convey the uncertainty of this information visually. The remainder of the article is structured as follows: Section 2 explains what we know about waggle dance, and describes our method to visually track and record a waggle dance. Then, Section 3 presents three methods to summarize and visualize this raw information in a GIS, with their advantages and drawbacks. The final section draws some conclusions and discusses further research.

2 Decoding Honeybee Waggle Dance

2.1 Understanding Waggle Dance

Apis mellifera bees perform three types of dances: the round dance, the sickle dance, and the figure-eight dance, the one usually referred to as the waggle dance (Figure 1).

The round dance is used to indicate resources in a radius of 50m around the hive, and the sickle dance usually indicates resources between 50 and 150m around the hive (Von Frisch, 1965). The figure-eight or waggle dance is used to indicate distant resources, further than 150m, and this is the one we focus on in the current study.

The waggle dance is composed of several runs or phases, and each run or phase indicates the location of the foraged resource. By repeating the runs in a dance, the bees make sure to recruit as many fellow bees as possible. The waggle dance is composed of two steps: (1) the bees go straight in a specific direction, wriggling the abdomen and the wings; (2) then, they stop wriggling and turn back to their starting point to begin a new run (Figure 2). The orientation of the wriggling portion of the run indicates the azimuth of the foraged resource, while the duration of this portion of the run indicates the distance from the hive to the resource (the longer the wriggling, the further the resource) (Landgraf et al., 2011; Couvillon et al., 2014; Wario et al., 2015)

However, geolocating the information decoded from the waggle dance is not straightforward because the indications given by the bees are uncertain, with additional uncertainty deriving from the decoding process. The waggle dance only indicates a vague area; once arrived in this region, the bees are guided by the pheromones left by the nestmates that foraged the resource previously (Tautz, 2022). The variability and uncertainty of the angle and distance indication have been experimentally measured with harmonic radars to track the actual distance travelled by the bees (Riley et al., 2005): for a distance to the resource of 200m, the bees in the experiment flew $206 \pm 53m$. Within a single dance, some inconsistencies usually also occur between the indications given by each run (Couvillon et al., 2012). Some researchers specifically focused on the odometer of bees, i.e. the matching between the duration of the waggle run and the actual distance to the resource. It was shown that the obstacles on the route have an influence over the odometer (Srinivasan et al., 2000). Others defined a calibration curve of the odometer, based on experiments (Schürch et al., 2013), and we used this calibration curve to decode the distance in our study.

2.2 Tracking Waggle Dances in Video Recordings

Observation hives have long been designed to help humans observe bees (Galopin et al., 2023), and modern versions allow video recording of the dancefloor, i.e. the vertical frame where the bees perform most of their waggle dances (Wario et al., 2015; Galopin et al., 2023). These videos are recorded with a camera located perpendicularly to the dancefloor, allowing an assessment of the parameters of the waggle dance.

Though research exists to automatically detect the waggle dance instances in such videos (Wario et al., 2015), these techniques are not mature yet, and do not perform well on videos slightly different from the ones used for their design. This is why we rather adopted a human-based protocol to track waggle dance instances, and decode them. As there are many bees to track on the dancefloor on such videos, the first step is to divide the dancefloor into several regions that will be observed sequentially (Figure 3). As we observed that the density of bees was higher in the bottom two-thirds of the dancefloor, we divided the top third into three cells, and the bottom two-thirds into 3*5 smaller cells.

Then, we observe each cell in slow motion, using the open source tool Kinovea[1], dedicated to the analysis of the detailed movements of athletes. Kinovea allows the annotation of the video within timestamps, and also geometrical measures, such as angles and distances in one frame of the video. So, once a waggle dance is found, two timestamps are added at the starting and ending frames of the waggle run, and an annotation is added on the thorax and the head of the bee, to get their coordinates in the screen. Then, the angle measurement tool is used to record the orientation of the dance (Figure 4).

To store all these annotations, we designed a database with three classes described in Figure 5. The main class is *Waggle Run* which stores all the decoded runs and their parameters. The clearness attribute is a boolean that states if the run was clear, or if the observer has a doubt on their decoding. A *Waggle Dance* instance is composed of several consecutive waggle runs from the same bee, with a type attribute that gives the type of dance performed: round, sickle, waggle, or inconsistent when the observer sees runs of different types.

3 Different Methods to Geolocate Dance Indications

3.1 Geolocate Full Dances

As all waggle runs in a single dance are supposed to indicate the same resource, our first method consists of an aggregation of the coordinates indicated by each run of the dance. We could use the average angle and distance to find the average location of the dance, or even compute the centroid of the set of points from the runs, but these solutions did not properly convey the variability in the distribution of run positions. This is why we opted for a representation inspired by box plots, showing the median location, on top of a portion of the annulus defined by the 1st and 3rd quartile angles and distances (Figure 6).

3.2 Clustering Waggle Runs

Figure 7 shows in a simplified drawing a realistic spatial distribution of the locations of the waggle runs decoded from a video in an observation hive. The spatial distribution is heterogeneous and anisotropic. You can see clusters that probably correspond to foraging sites, places without points (e.g. the pond in Figure 7), places where the density

[1] https://www.kinovea.org/

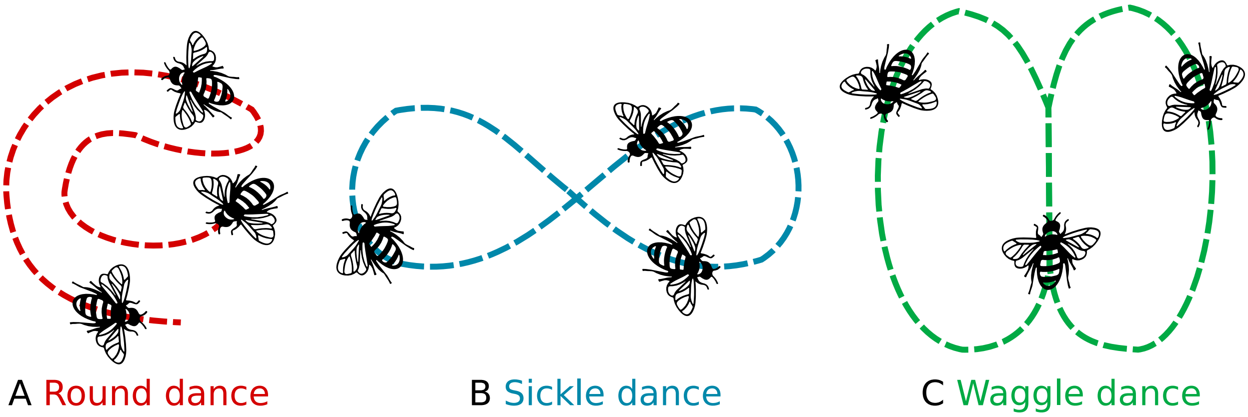

Figure 1. The three types of dances: the round dance for very close resources, the sickle dance for close resources, and the waggle dance for distant resources.

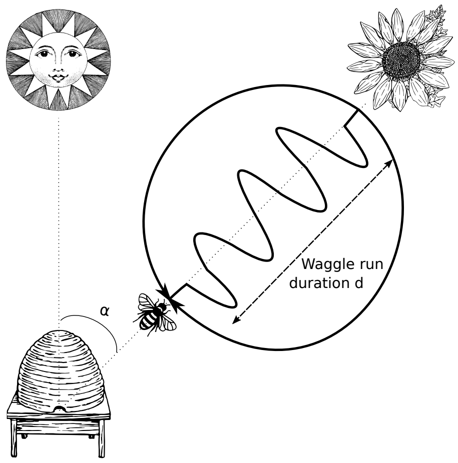

Figure 2. Principles of the honeybee waggle dance. The honeybee makes a waggle run, and then comes back to the starting point for another waggle run. A dance is composed of multiple consecutive runs indicating the same resource foraged by the honeybee. α corresponds to the azimuth of the resource indicated by the honeybee, while the duration d is related to the distance from the hive to the resource.

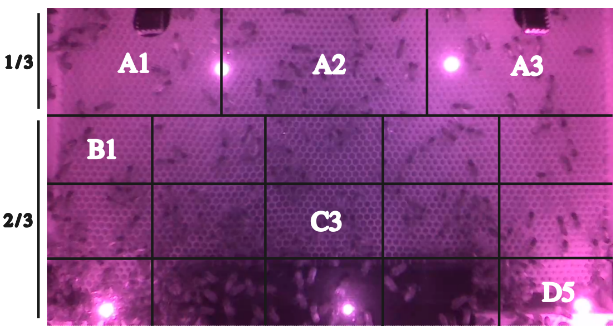

Figure 3. The filmed dancefloor is divided using a grid with the top third of the dancefloor containing larger cells as bees dance more in lower parts of the dancefloor.

of points does not correspond to a clear cluster, and even isolated points.

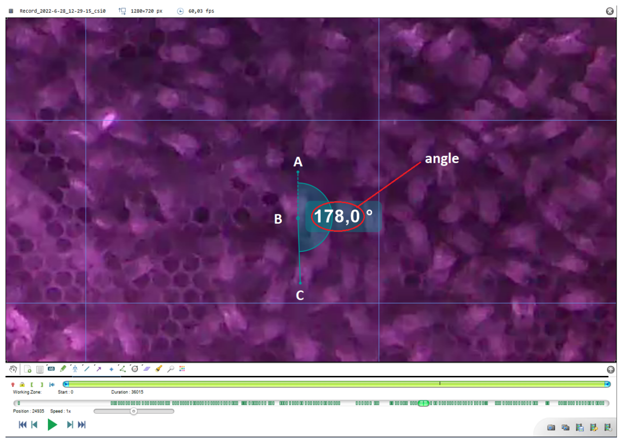

Figure 4. Annotation of the orientation of a tracked waggle dance using the Kinovea software.

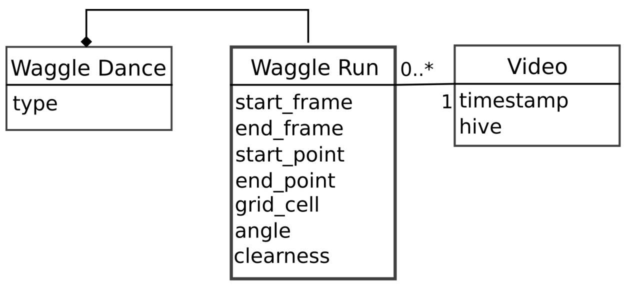

Figure 5. Simplified UML diagram representing the schema of the database storing the waggle runs and dances decoded from the videos.

In this case, we want to focus first on the clear regions containing foraging sites, i.e. clusters of points. This is why we propose to cluster the points corresponding to a waggle run. We are not interested in the spatial outlier points that either correspond to minor resources, to an imprecise decoding of the waggle run, or to an imprecision from the bee. This is why clustering methods that ignore outliers such as DBSCAN (Ester et al., 1996), or OPTICS (Ankerst et al., 1999) are preferred. Depending on the timespan of

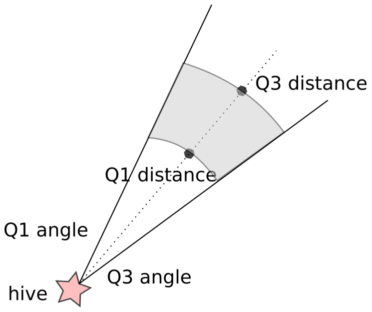

Figure 6. Principles of the boxplot representation of a waggle dance: like in a statistical box plot, we use the boundaries of quartiles 1 and 3 for the angle and the distance, and the dance is represented as a portion of an annulus.

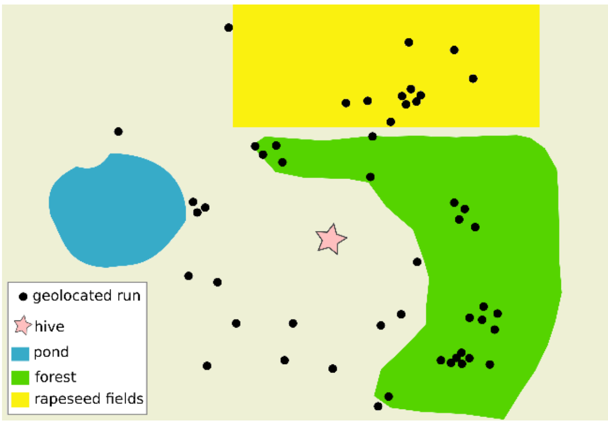

Figure 7. Simplified drawing of a hive surrounded by the points geolocating waggle runs. Due to the uncertainty of this communication and of its decoding, not all points correspond to actual foraging sites.

the clustered waggle runs, we can opt for a purely spatial clustering, or a spatio-temporal algorithm, such as ST-DBSCAN (Birant and Kut, 2007).

3.3 Heatmaps of Waggle Runs

Heatmaps are a usual visualization technique to show density differences, in particular with a point cloud. In this case, the heatmap is computed using the kernel density estimation method, to better control the smoothness of the result. The points located outside the grid cell (or pixel) but close to it, influence the value of the pixel, with a decay depending on the Kernel function used (Figure 8).

For the size of the pixels, we recommend a value around 1-2 meters, and for the radius of the kernel, we recommend 75 meters, based on the experimental observation of the variability of distance indications (Riley et al., 2005).

3.4 Use Case and Results

We tested our method with videos recorded thanks to an observation hive that we developed called GeoDanceHive

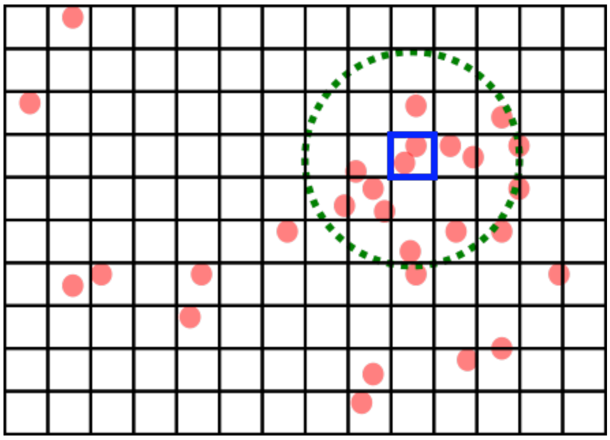

Figure 8. Principles of the kernel density estimation method for heatmaps: the value of the blue pixel in the grid is related to the two points located inside the pixel, but also to the points inside the kernel (green circle).

(Galopin et al., 2023), installed with other normal hives in a rural environment. The details of the site and the hive are anonymised during the review process. The videos are recorded using the MPEG-4 format, with a h264 encoder, and the frequency is 60 fps, which is sufficient to observe the waggle dance. The image resolution is 720p, i.e. 1280 x 720 pixels, with a spatial resolution of around 1.76 px/mm. We decoded 11 videos scattered on four different days. These videos were chosen because they contain many visible dances, which is not always the case due to weather conditions.

Figure 9 shows the box plot representation of the dances from one of the videos. The box plots were obtained with a Python script using open-source libraries. We can see from this example that the variance in distance and angles can be very high in some cases, making the interpretation of the dance very complex.

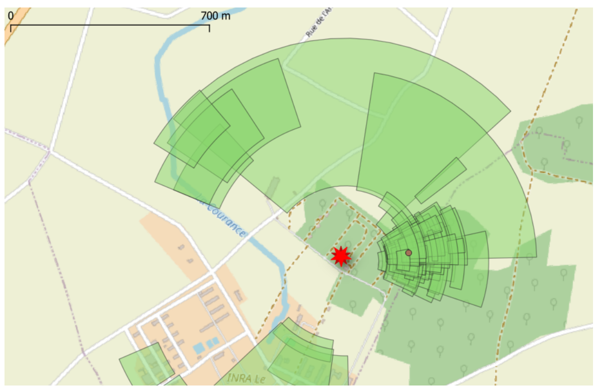

Figure 9. Results of the dances representation for the video of 21/06/2022 (background map: ©OpenStreetMap contributors). The red star symbol shows the location of the hive, and the brown circle shows the location of the feeder that attracted most of the dances.

Figure 10 shows the clusters obtained on the runs from one of the videos. The DBSCAN algorithm was used with a threshold distance of 50 m in a cluster, and a minimum number of 5 runs in a cluster. Even though many of the runs are considered as outliers, the result shows that clusters point at locations which are probably foraging sites.

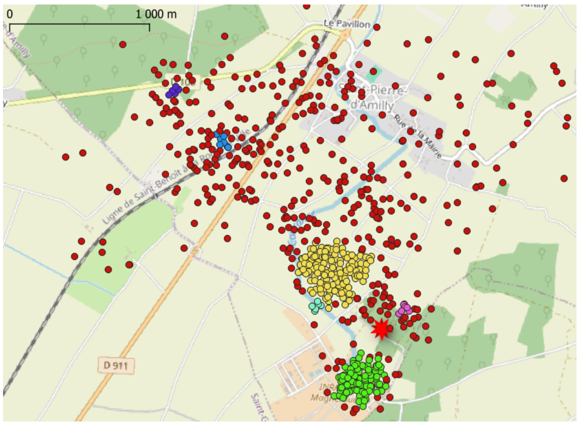

Figure 10. Results of the clustering method for the videos of 28/06/2022 (background map: ©OpenStreetMap contributors).

Finally, Figure 11 shows the results from the heatmap method on the same video as the previous clustering result. The hotspots in the heatmap can be used to find the foraging sites of the bees on that particular day. The heatmap was obtained with a kernel radius of 75 m, a pixel of 2 m, and a quartic kernel function.

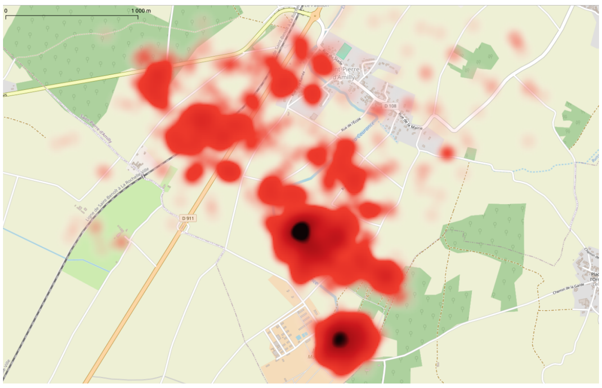

Figure 11. Results of the heatmap method for the videos of 28/06/2022 (background map: ©OpenStreetMap contributors).

On one of these four days (21/06/2022), we also installed an artificial source of food, called a feeder, 230m from the hive. On that day, most of the dances point at the feeder, so it is a good way to assess our localisation methods. Figure 12 shows that both the clustering and the heatmap point clearly to the location of the feeder.

To further test these three methods, we organised field surveys where biologists tried to precisely identify the nature of the foraged sites based on the maps of the runs or dances. One field survey was made with each of the methods, using a tablet with QGIS.

The waggle dance representation was considered as not precise enough as it is frequent to have outlier runs in a

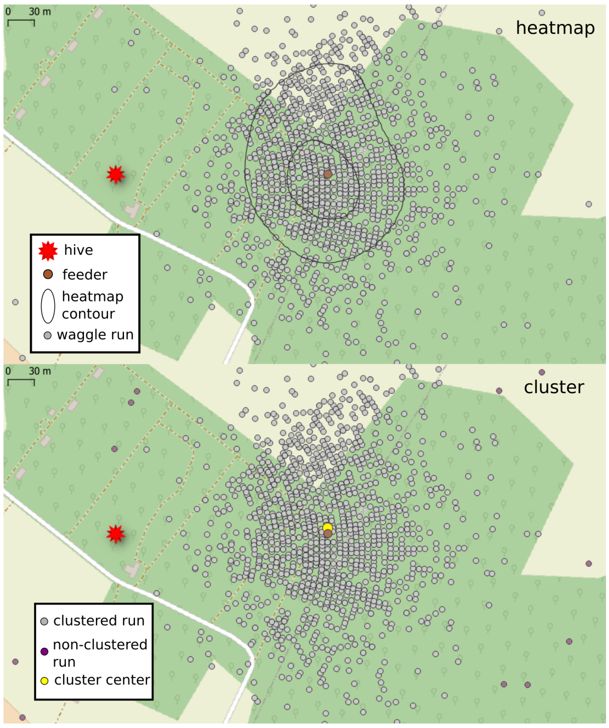

Figure 12. Comparison of the heatmap (represented by contour lines) and clustering methods for the video of 21/06/2022, where a feeder was used (background map: ©OpenStreetMap contributors).

dance. The box-plot representation was often too large to explore, and the foraging site was often not found on the field.

The clusters of waggle runs were useful to find a rough location of the foraging sites, but often this method causes some drifts compared to the real location of the foraged site. It was not very practical to find the precise location as there is no way to zoom into clusters while you are near the site to find the exact location.

The last method, with heatmaps of waggle runs, was considered by the participants of the field evaluation as the best to find the foraging sites. However, it was not easy to process for our field operators because it covers the background map, and requires some opacity adjustments on the map.

3.5 Data and Software Availability

The data and the code used in this research can be found on Zenodo (https://zenodo.org/doi/10.5281/zenodo.10590028).

4 Conclusion and Future Research

In conclusion, geographical information science can be useful for studying bees and this research proposes first methods to geolocate the uncertain information decoded from the waggle dance. In particular, our experiments show that we should not try to represent waggle runs grouped as dances.

To go further, we plan to assess the different methods more deeply with potential users of foraging maps, e.g. beekeepers. We also plan to develop new methods that integrate the geographic data representing the bees' environment, as landcover information could guide the probability of the location of foraging sites. We also plan to develop multi-scale versions of our methods, as the field survey showed that broad and detailed views of the foraging sites were necessary.

Regarding the communication between bees, we focused in this research on the geolocation of the waggle dance, though some round and sickle dances were decoded. Studying how these types of dances could also be geolocated would be important.

Finally, the most tedious part of this research was the visual decoding of the dances in the recorded videos, and we plan to use deep video segmentation techniques to detect the dances and their properties automatically.

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Competing interests. The authors declare that no competing interests are present.

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