Analysis of a natural honeycomb by means of an image segmentation

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Abstract: The paper is applying a method of image segmentation to the study of the size of the natural honeycomb structures. The proposed segmentation is based on a thresholding of the original image of the honeycomb, which is turned into a binary black and white image. This binary image is further partitioned into multiple sets of pixels, known as "super-pixels", each containing a cell of the honeycomb. Each super-pixel is characterized by a label, and to each label corresponds the size of the cell. In this manner, we can easily measure the size of each cell of the honeycomb and distinguish the cells of the workers from those of the drones.

Keywords: Image Processing, Image Segmentation, Natural Structures, Bees, Animal Production Studies, Agricultural Science, Apis Mellifera, Cell Size, Brood Combs.

A honeycomb is the hexagonal arrangement of cells made of wax, built by the bees in their nests. These cells are used to host the larvae and to store the honey. To secrete the wax for the honeycomb, the bees are largely consuming the honey that they produce [1]; for this reason, the wax structure is left intact, in its most part, when the honey is extracted by the beekeepers, so that the bees have not to reconstruct the entire structure. Let us observed that some wasps construct hexagonal combs too, but they are made of paper instead of wax. Some species, such as that of the Mexican honey wasps [2], are storing the honey in the nest, technically forming a paper honeycomb. Sometimes then, the term "honeycomb" is also used for such structures.
A common explanation exists as to why honeycomb is made of hexagonal cells. The hexagonal structure is giving a partition of a surface with equal-sized cells, which are minimizing the total perimeter of the cells. This is known as the "honeycomb conjecture" [3-5]. Thus, the bees need to use in the hexagonal structure the least material to create the cells within a given volume. Another explanation was given by D'Arcy Wentworth Thompson [6]: the hexagonal shape simply results from the process of individual bees putting the cells together. The process is somewhat analogous to the lattice that we can see appearing in a field of soap bubbles.
The individual cells have not a geometric perfection, and therefore, in a regular honeycomb we can observe deviations of a few percent from the "perfect" hexagonal shape [7]. Moreover, in the transition zones between the larger cells of drone comb and the smaller cells of worker comb, or when the bees encounter obstacles, the shapes are often distorted.

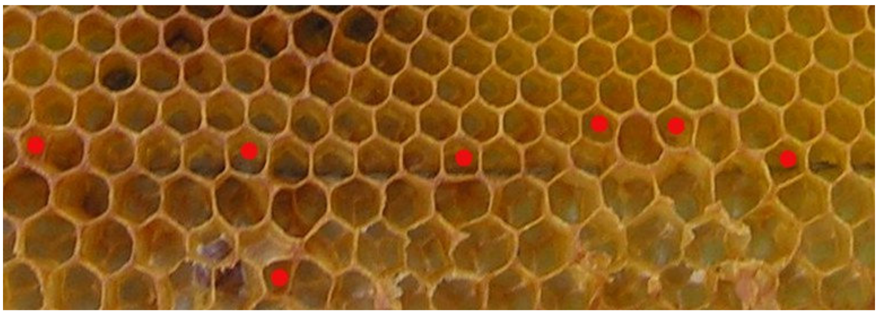

Figure 1: Here we can see a honeycomb containing transition from worker to drone cells. Where there is the transition, the bees make irregular and five-cornered cells, that in the image are marked with red dots. (Image Courtesy, 2011, Audrius Meskauskas, Wikipedia).

When the cells are used as brood comb, the queen bee lays eggs in them. The cells for the brood comb vary in diameter: the size ranges between less than 4.6 millimeters to greater than 6 millimeters [8]. As we can see in the Figure 1, the drone bees require the largest cell size. Some evidence suggests that a smaller cell enables faster development time from egg to a fully developed, adult bee [9]. A detailed discussion and data of the cell size are available from [10]. The cells in honeycombs has been recently studied also in [11]. In

these references, the authors obtained the size of the cells by a direct inspection of the samples and by the use of a ruler.
In fact, the measurement of all the cells is a quite long work; we could ask ourselves whether an automatic method, based on the image processing for instance, could be helpful in such studies. The answer is positive.
Let us follow the approach of an image segmentation, as proposed in [12]. In image processing, a segmentation is a process of partitioning an image into multiple sets of pixels, that are defined as super-pixels. Each super-pixel is characterized by a label or parameter. In [12], we have proposed a method for determining the super-pixels based on the thresholding of a grey-scale digital image. Thresholding is obtained using a clip-level (the threshold value), according to which the greyscale image is turned into a black and white image. First of all then, let us see how the Figure 1 becomes after its conversion in grey tones and thresholding. Here the result is given in the Figure 2. The cells which are crossed by the image frame have been removed.

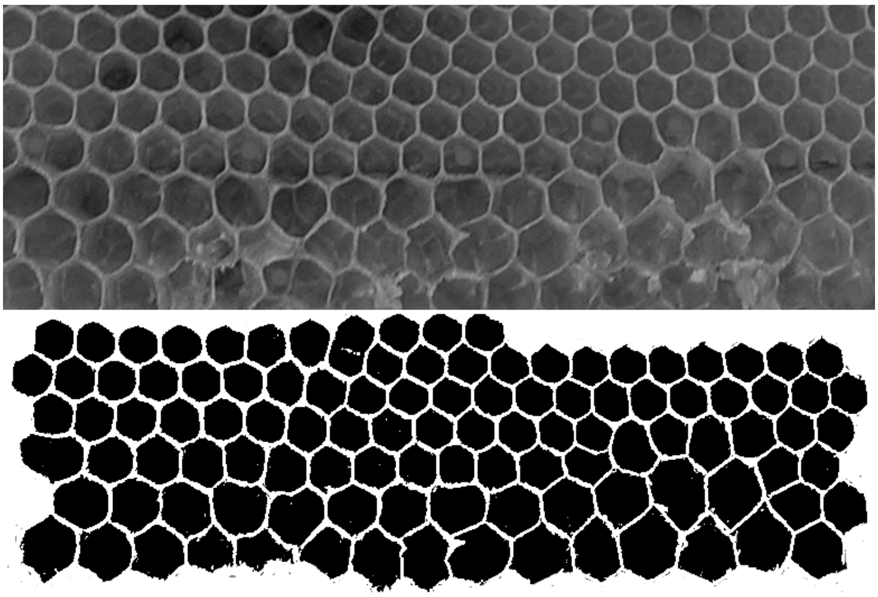

Figure 2: Thresholding of the image in the Figure 1. The original image is converted into a greyscale image which is reduced to a black and white image. The cells which are crossed by the image frame are removed from the binary image.

The black pixels of the Figure 2 are analyzed according to [12], to subdivide them in super-pixels. Each of the super-pixels has a different label. If we use the colour tones to render the super-pixels, the result is like that given in the Figure 3.

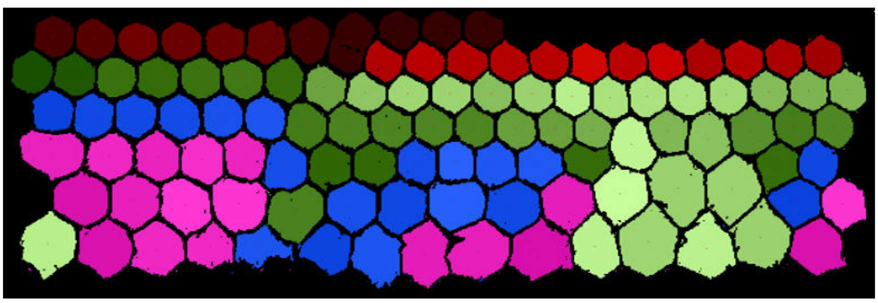

Figure 3: The black pixels are grouped into super-pixels. Each of them is colored with a different colour tone.

As we can see in the Figure 3, each super-pixel corresponds to a cell of the honeycomb structure. It is therefore quite simple to deduce the size of each cell, because it is the size of the corresponding super-pixel. We can plot the areas (in pixels) corresponding to the labels (Figure 4).

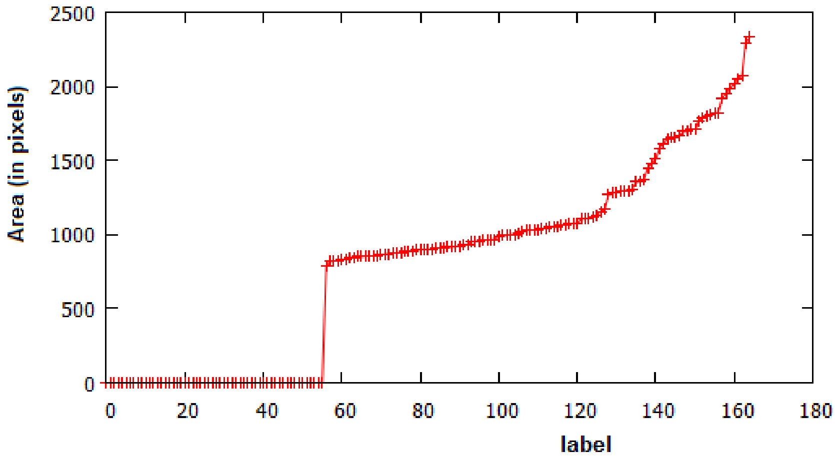

Figure 4: Size (in pixels) of the super-pixels for the given labels.

We can also plot the distribution of the super-pixels, and consequently their frequencies, for given sizes of the cells (Figure 5). From this plot, we can appreciate the regularity of the small cells, those of the workers, that we find in the honeycomb of the Figure 1. The drone cells have a larger distribution of sizes.

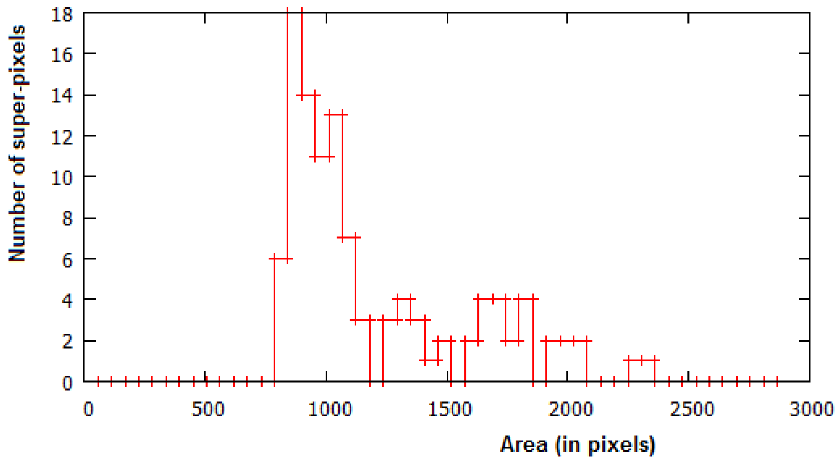

Figure 5: The distribution of the super-pixels according to their size.

In the following Figure 6, we are giving some of the areas of the super-pixels (let us note that the values are the numbers of black pixels composing the super-pixel).

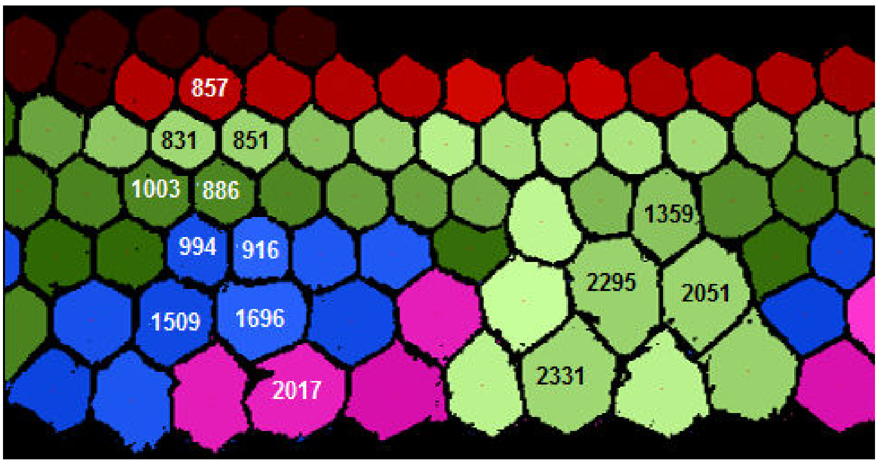

Figure 6: Some of the areas of the super-pixels. We see the numbers of black pixels composing the super-pixels.

The results given above are showing that we can use one of the fundamental methods of the image processing, the segmentation of the images [13,14], to evaluate the distribution, in size, of the natural honeycomb cells. The proposed approach can be interesting for the numerical and statistical analysis of the brood combs and the role of the size of the cells in the beekeeping [15-18].

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