SPATIAL OPTIMIZATION FOR ORCHARDS IN COMPLEX FIELD AREAS

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ABSTRACT

The establishment is a cornerstone work for orchards and paradoxically is mainly based on empirical and traditional knowledge. This results to low or no improvement at all over the years and even less likelihood to adopt and harness the power of the new technological breakthroughs. The proposed system takes advantage of the abundant computational power to recognize and adapt planting patterns to complex field shapes. Enhancements include among others the integration of new spatial work requirements stemming from the emergent agri-robotics machinery field that can be input data for the design process. Also, the ability to dry run different planting patterns to fully optimize surface coverage. Furthermore, the work includes modules that quantify and integrate micro-climatic factors, optimizing in a non-uniform method the planting pattern. This feature is ground-breaking especially in cultivations that require pollinators, where standard practice was to set a percentile of pollinators, severely affecting productivity. In the work presented the algorithm is shown to be able to reduce the number of pollinators without decreasing their effectiveness, using grid deformation techniques, clustering algorithms with modified criteria imposed by the needs of the agronomic system. The results show significantly increased productivity potential attributed both to the reduced number of pollinators required and the increased spatial efficacy. Additionally, the fully digitized operation offers enhanced postprocessing capabilities to the farm manager as well as a digitized ground truthing tool.

Keywords*:* orchard, establishment, spatial, optimization, algorithm**.**

1. INTRODUCTION

Orchard cultivation has increased in the last 25 years both in area coverage and in crop production. This is verified by statistical data provided by FAO. For three major categories of orchards, fruits, olives and hard-shell nuts data show that the area used for each has increased by 32%, 42% and 32% respectively, depicting a clear shift towards orchard cultivations. Orchards have been studied in depth due to their long economic lifespans and the limited ability to be take corrective actions after their establishment. This particular feature has fuelled development of early algorithmic tools to pre-plan planting patterns, randomising spatial arrangement and ensuring bio-diversity (Giertych, 1975; Bochtis et al., 2007). Initial work was further extended and evolved to permuted algorithms (Bell and Fletcher, 1978) laying ground for development of algorithmic tools for agriculture. Increase of computational power and advances in computational frameworks led to modern heuristic based approaches

(Chaloupková et al., 2016) and to simulation tools that can predict efficiency of spatial arrangements (Bochtis et al., 2009, 2010, Hameed et al., 2010, 2012, 2013; Sáez et al., 2018).

Simultaneously robotic applications are being developed for all cultivations and with some focusing particularly on orchards (Fountas, Søren Pedersen and Blackmore, 2005; Won Suk Lee, Chinchuluun and Ehsani, 2009; Bochtis et al., 2015). To build and sustain a fully automated system in agriculture, the need for planning with the aid of algorithmic tools is increasing. In this light, the work presented will address the problem of establishing an orchard taking fully advantage of the available technologies and output an optimised planting pattern that contains all the necessary information for autonomous or conventional agricultural machinery to execute the task.

2. Methodology

To develop an algorithmic tool that covers all the targeted operations related to the orchard establishment we identified four major groups of functionalities as seen in Figure 1. The first group of parameters refers to plot geometry that needs to be defined by the user as an entity and provide extended information. The second group refers to the planting pattern that will be used, followed by the climatic constituent (Third module). Lastly, the fourth module pulls data from all the other modules to produce the optimal positions for pollinator placement. The modules will be explained in more depth in the sections that follow, as well as their interdependencies that will become evident as the algorithm is described in detail.

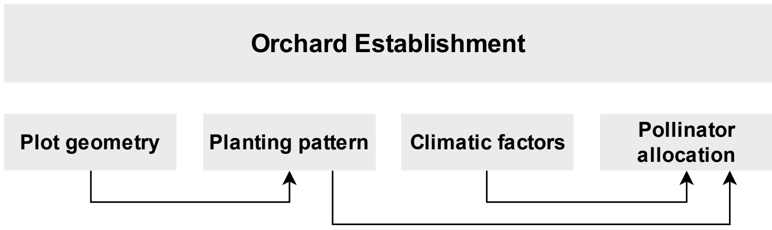

Figure 1. Four groups of functionalities

2.1 Plot geometry

The shape of the plot has a significant impact on planting operations. Even though orchards differ from arable farming considerably, the requirement for machinery to be able to access every point in the orchard is still fundamental, even more in a precision agriculture (PA) framework where machinery equipped with the respective implements need to be employed. Consequently, the design of the orchard needs to facilitate these needs and furthermore foresee the requirements of future machinery, since as mentioned above orchards are long-term investments. In a 20 to 25 years timespan disruptive technological advances are to be expected and therefore need to be factored in the planning stage. The initial input to the system is the set of coordinates that define the plot in question. The To ensure maximum compliance with the user's position towards innovation and future planning, the software doesn't force the optimum solution on the user, instead it asks for user input to define the primary parameters of the field, namely entry-exit point and major direction. These two elements define the starting point of the planting and the direction of rows. Compliant to empirical practices, the direction of rows is defined uniquely by user input that indicates the approximate direction, which is used in a calculation based on plot coordinates to fully define the exact direction and align the rows to the user selected plot side. Completing this module are the data related to headlands and side offsets, which are freely defined by the user.

2.2 Planting pattern

Having delineated the planting areas and their headings, the user needs to input data regarding the planting pattern. By entering the inter-row and the intra-row distance the pattern is fully defined, and the algorithm can populate the matrices related to the particular plot. The tree placement is confined by the plot and the respective offset distances entered in the initial module. Furthermore, the heading of the planting also influences the planting pattern. To reduce computational cost and round-off errors, the algorithm works selectively in the absolute and a relative coordinate system whichever provides the maximum benefit.

2.3 Climatic factors

Integrating climatic factors into the algorithm introduces the weighting system that the pollinator allocation module is going to use to enhance allocation by taking into account enhanced meta-spatial information. To quantify the effect of climatic factors, a weight function is introduced that takes into account the type of parameter that is being introduced and the relative position of trees in the orchard. The resulting matrix is a temporal dimension related to the climatic factor, normalized for simplified use as a weight function. This is the final computational step that requires user input for data, since the fourth module uses the data computed on the first three and modified clustering algorithms to achieve output results, without the input of the user.

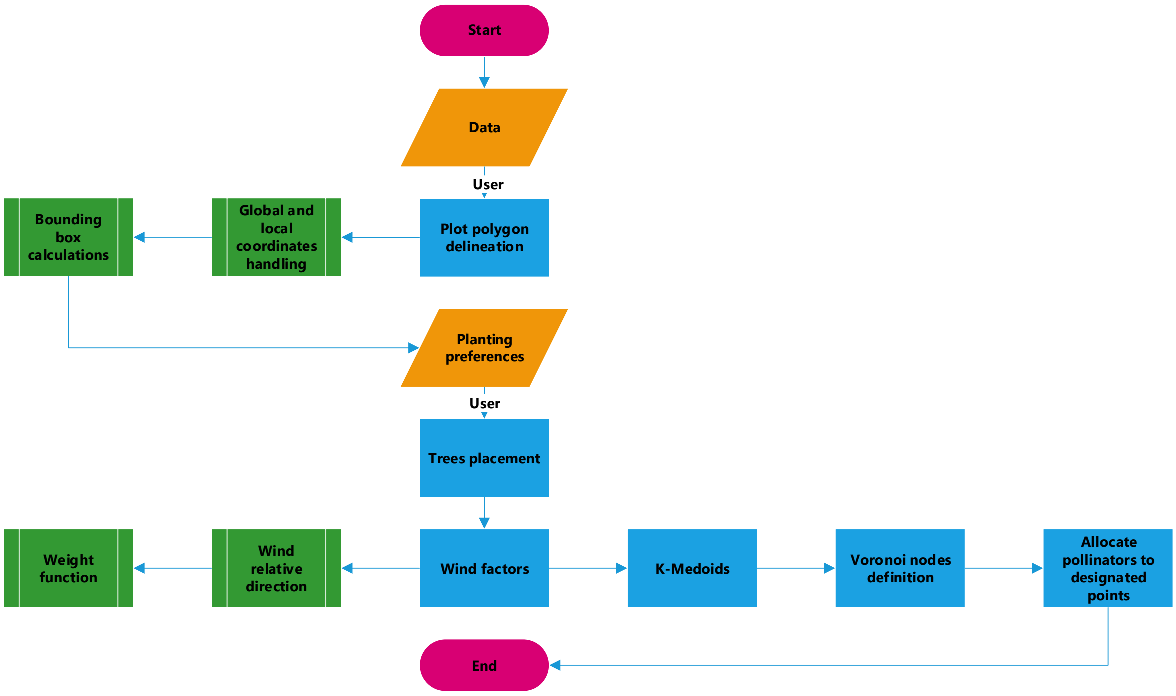

Figure 2. Flow chart of the proposed method

2.4 Pollinator allocation

In empirical practices pollinators are planted at regular intervals since the requirements for their function is defined solely by their percentile in the orchard. Uniform allocation ensures a degree of homogeneity for the field and in some cases, this leads to the dedicated use entire rows for pollinators. In this work, pollinators are placed either by spatial clustering using Voronoi polygons or according to their functional potential that is strongly influenced by wind direction and speed. This dimension is included with the use of weights. The method we implemented for allocating pollinators is a reverse approach to the problem, wherein clusters of trees are formed according to their position and their weights. The number of clusters N is calculated by the percentile of pollinators needed for the cultivation. The clustering algorithm used is a modified K-Medoid, producing clusters of defined minimum size with the centroid of the cluster designating the pollinator position. The flow chart for the proposed method is shown in Figure 2.

3. Results

The algorithm was run to plot the tree positions using all three methodologies; empirical with a 25% of pollinators, Voronoi polygons clustering at 8% pollinators and modified weighted K-Medoids clustering at 8% pollinators. The inter- and intra-row distances were set to 8 meters and the diamond layout was chosen. The plot used is 200m by 400m and trapezoidal, resulting in 897 tree positions available.

To compare theoretical effectiveness a performance measure had to be defined. This was the mean distance of trees to the pollinator within the cluster. Despite the significantly lower percentile of pollinators, both Voronoi and modified weighted K-Medoids algorithms performed well and confirmed the improvement potential of the system. Results are shown in Figure 3 toFigure 6. Furthermore, mean distances and standard deviations are presented on Table 1. Allocation methods resultsTable 1.

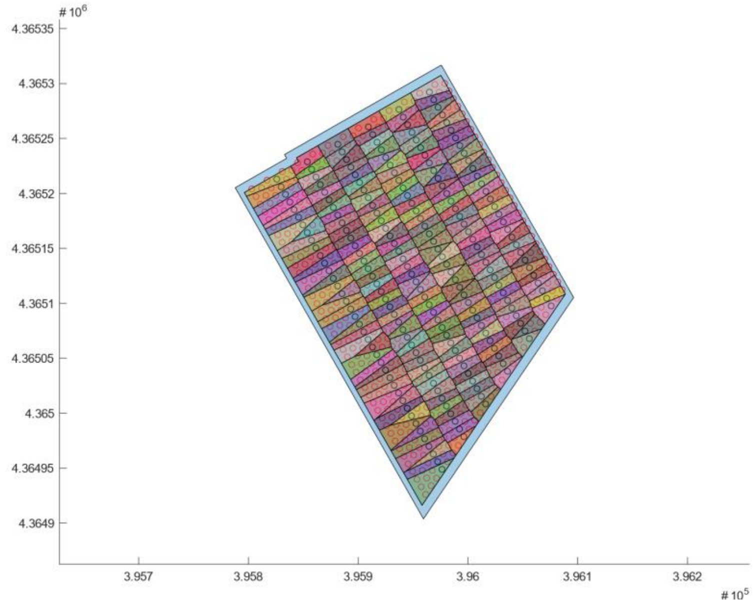

Figure 3. Empirical allocation of pollinators

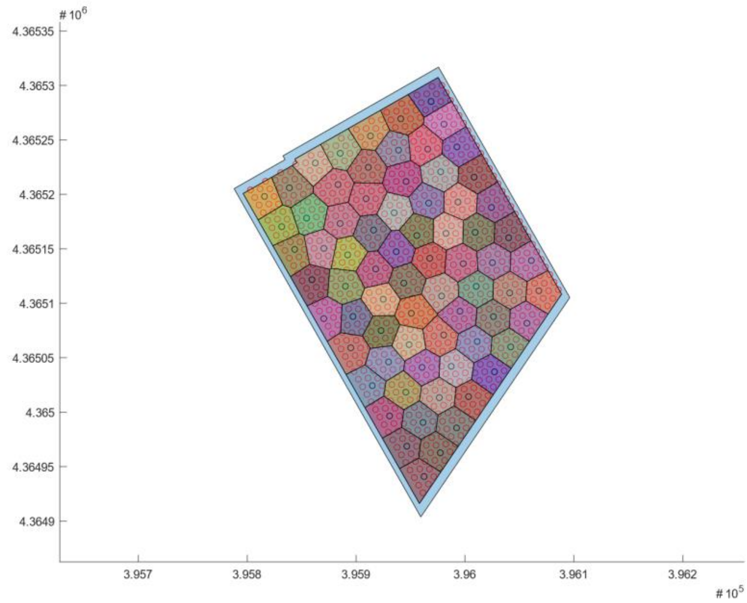

Figure 4. Voronoi allocation of pollinators

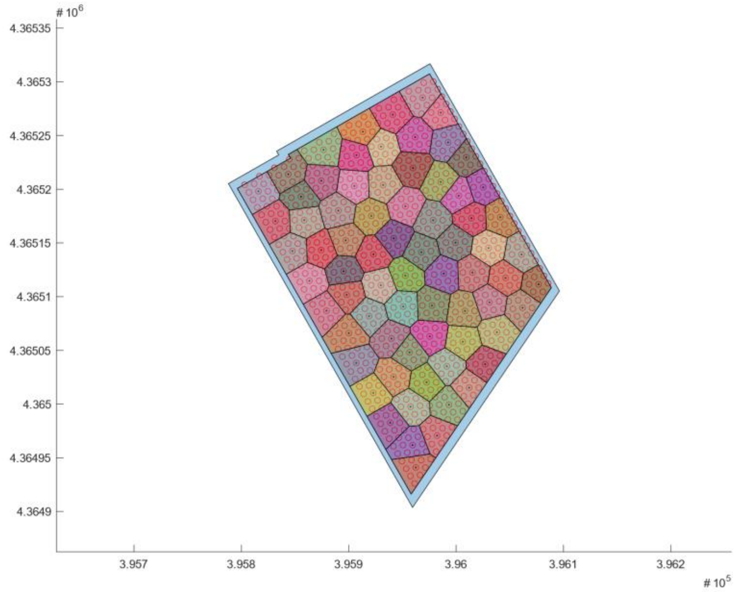

Figure 5. K-Medoids allocation of pollinators

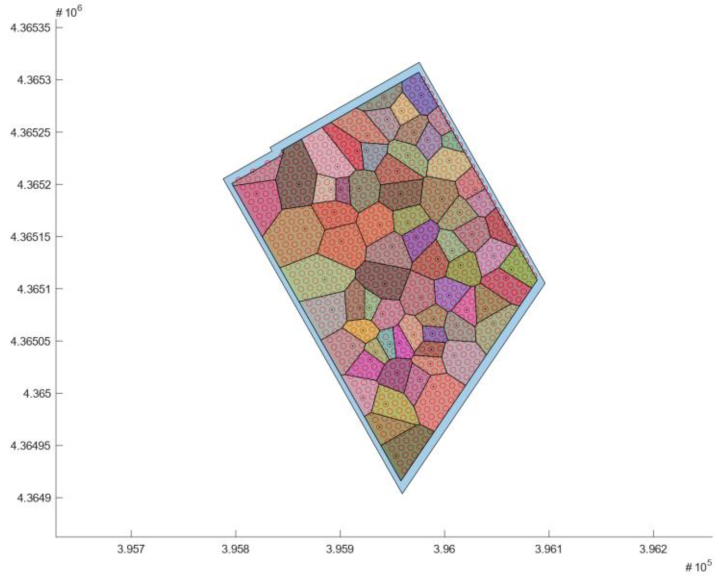

Figure 6. Weighted K-Medoids allocation of pollinators

Table 1. Allocation methods results

Method	Pollinator percentage	Mean distance to pollinator (m)	Standard deviation (m)
Empirical	25%	12.29	4.57
Voronoi	8%	10.81	4
K-Medoids	8%	11.88	3.43
Weighted K-Medoids	8%	15.47	8.48

4. Discussion

Compared to the empirical method, both methods proposed have given promising results. Taken into account that all new methods proposed have 66.67% less pollinators, they outperform empirical pollinator allocation. Voronoi and K-Medoids clustering actually performed even higher than the empirical method. Weighted K-Medoids is still performing higher than the empirical method when the percentile of pollinators is considered, however the potential of this method needs to be assessed by experimental data. Direct comparison would require to transform the other layouts to the curvilinear coordinate system and calculate metrics based on it. The weighted method was optimized on this coordinate system, which would result to all other methods being at a significant disadvantage.

5. Conclusions

To fully evaluate the comparative advantage of the weighted K-Medoids pollinator allocation method, experimental data need to be processed that will justify the comparison on the curvilinear coordinate system that this method relies on. However, the value of spatial optimization, even in the care of the weighted method, is clear. The increased number of productive trees in an orchard is a significant gain for the multiyear cultivation. Designing with the help of digital tools allows for both digital documentation of the orchard, providing downstream usability, and for dry-running layouts without the longtime commitment of applying them in practice.

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