Giuseppe Pellizzi Prize

CLUB OF BOLOGNA

EVALUTATION OF PROXIMAL SENSING TECNIQUES AND TESTING OF VARIABLE-RATE KIT FOR SPRAYERS TO IMPROVE ENVIRONMENTAL AND ECONOMIC SUSTAINABILITY OF CROP PROTECTION STAGES

Dissertation presented to University of Florence, Florence, ITALY

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1 Introduction

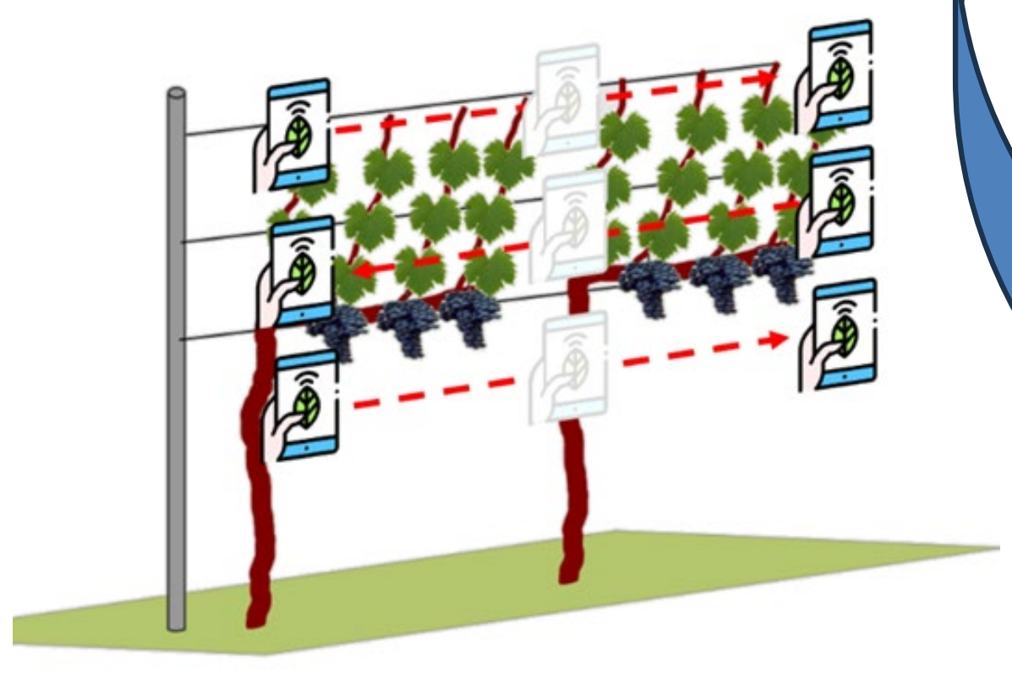
The objective of the PhD thesis, that is the development and evaluation of different proximal sensing tools for the characterisation of vine canopies with the aim of supporting the development, validation and testing of a Variable Rate Application (VRA) kit for sprayers to improve the environmental and economic sustainability of crop protection stages a collection of papers, is discussed in four scientific paper.

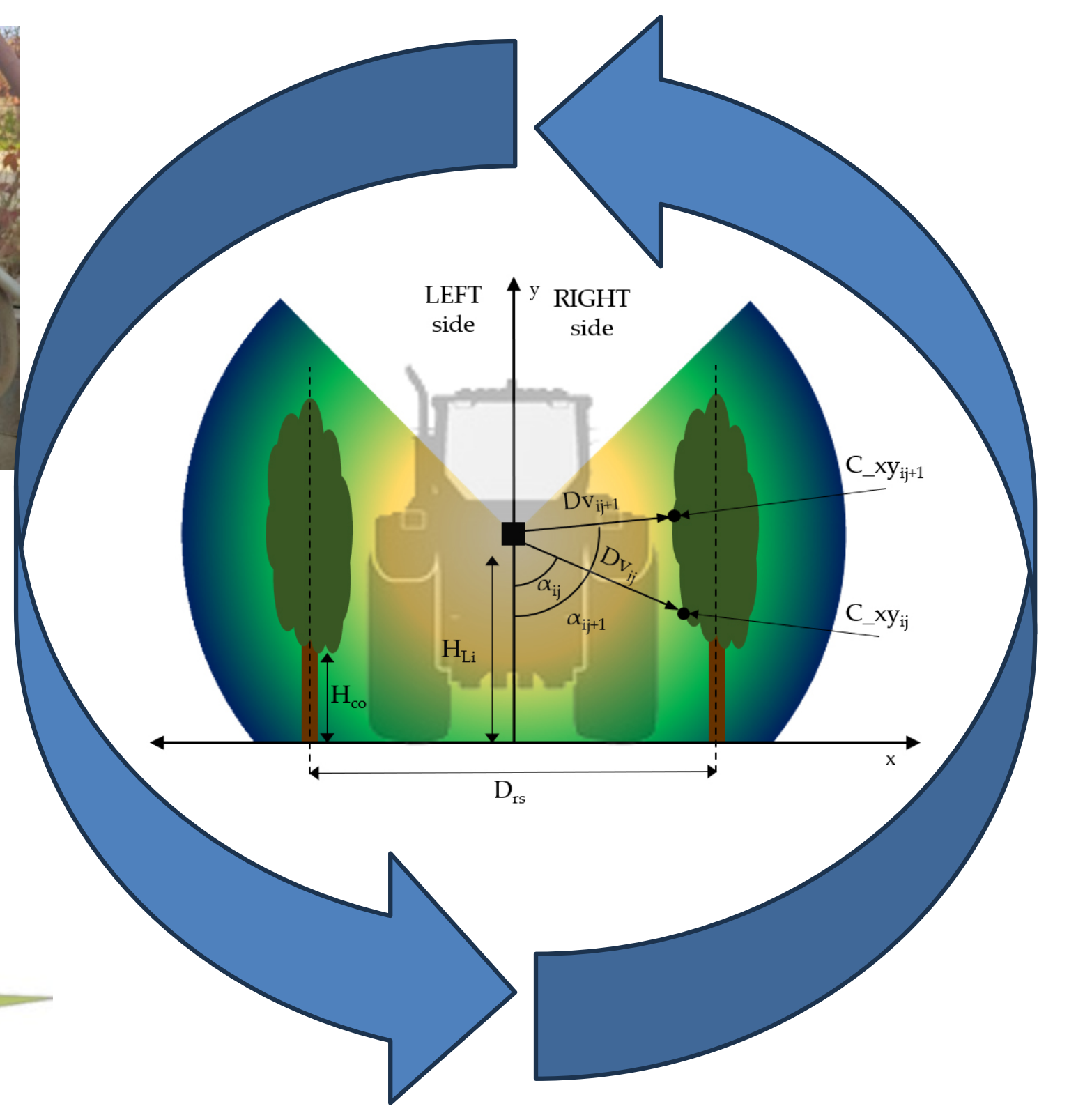
The detailed objectives of the PhD thesis have been carried out in four steps, corresponding to four papers.

- The development of an algorithm for characterizing the vine canopies in real-time with terrestrial LiDAR (Light Detection and Ranging) through the Tree Row Volume (TRV) index calculation.
- The assessing of the reliability of different 3D point clouds sources for vine canopy size assessment based on aerial and ground photogrammetry and mobile laser scanner.
- The assessing of the operative performance of a second-generation US in canopy characterization and to fine-tune the actuation range between US readings and applied volume of plant protection products.
- The development and the implementing of a VRA kit in a conventional sprayer and to assess its spraying performance and its economic sustainability in an entire crop protection season.

2 Development of an algorithm for assessing canopy volumes with terrestrial LiDAR to implement precision spraying

This work describes a LiDAR-based algorithm for the automatic characterization of the vine canopy. The aim of the present work was to develop and test an algorithm using a tractor coupled with terrestrial LiDAR (Light Detection and Ranging) and GNSS (Global Navigation Satellite System) technology, to simplify and automate the process of canopy volume acquisition and calculation. This system can acquire data at different scan intervals (from 0.05 m to 0.5 m) and subdivide the canopy volume calculation into different canopy bands (near-cordon canopy, intermediate canopy, upper canopy). To test the algorithm, the LiDAR-based volume was correlated with two manual measurements of canopy volume (tree row volume and point net cloud) on 26 specific vines. In addition, an overall assessment was carried out by evaluating the LiDAR-based canopy data of approximately 0.5 ha. The field tests were carried out in two vineyards with different row spacing and in three different phenological phases (BBCH 57, BBCH 71, BBCH 81). The results showed good correlations between manual and LiDAR-based measurements for both total canopy volume (R^2 = 0.67 and 0.56) and partial canopy volume (R^2 = 0.74). In terms of overall assessment, an average canopy volume of 0.282 m3 per linear meter of vine-row was detected in the BBCH 57 phase, compared to 0.385 m^3 m^{-1} measured in the BBCH 81 phase. The increase in canopy volume (from 0.282 to 0.385 m^3 m^{-1}) between the two phases was 37%, reflecting the natural growth phase of the vineyard. This increase was confirmed by the two manual canopy measurements. In conclusion, although the LiDAR-based algorithm works in automatic mode, the canopy volume approximation appears to be acceptable for estimating canopy volumes, with the advantages of a faster procedure and less laborious post-processing computations. Furthermore, the automatic calculation mode and the faster procedure simplify the canopy volume calculation, allowing its use in the development of real-time variable rate systems.





4 Second-generation ultrasonic sensor in precision spraying, testing and actuation range refinement

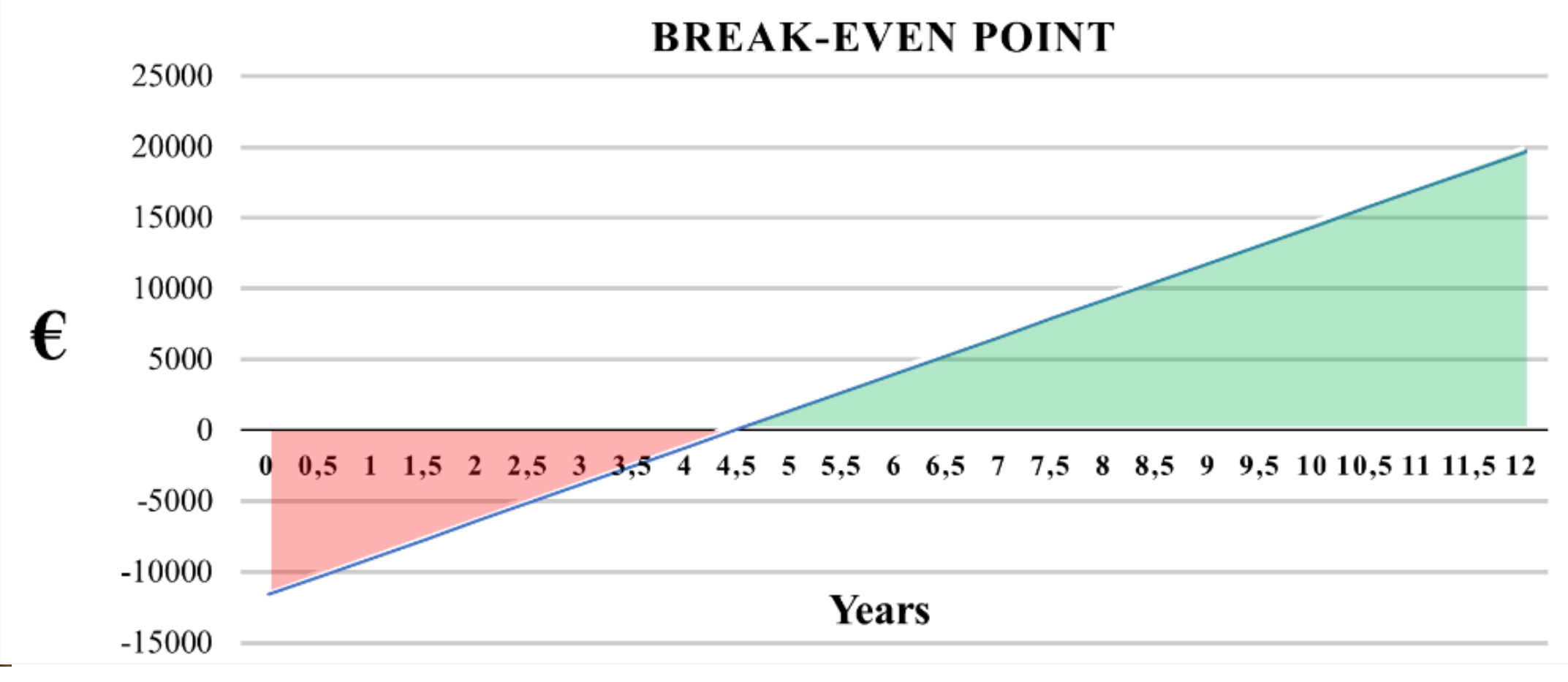
An innovative Ultrasonic Sensor (US) was tested for canopy characterisation. This sensor can directly distinguish the foliar layers, canopy envelope and canopy density (Edges, Envelope and Density) by measuring the number and intensity of echoes in a pre-selected region of interest. Therefore, the main objective of this study was to correlate the US readings with manual canopy indices (Thickness, Height and TRV). The US readings were then related to the spray rate, with the aim of future implementation of the US in a VRA sprayer. The field tests were carried out in a cordon spur vineyard in three different phenological phases and consisted of two parts: one dedicated to comparing US readings with canopy characteristics; one dedicated to refining the spray range through the analysis of artificial targets (plastic collectors and water-sensitive papers) using spectrophotometry and image analysis techniques. The results showed interesting correlations, between canopy height and TRV and US parameters (R^2 > 0.7 and R^2 > 0.6, respectively), indicating good reliability in canopy characterisation. To verify the correct amount of spray in relation to the canopy dimensions, twenty vines were sprayed at three different application rates in each phenological phase. Through this analysis, two actuation ranges, based on normalised deposition and spray coverage parameters, were obtained between US readings and spray volumes applied. This made it possible to refine the spray rates in relation to the US readings, thus enabling the use of this sensor in a VRA sprayer.

3 Comparison of Aerial and Ground 3D Point Clouds for Canopy Size Assessment in Precision Viticulture

Having tested the reliability of the LiDAR-based algorithm in canopy assessment, the next step has been to further investigated the evaluation of the LiDAR-based technology (Mobile Laser Scanner - MLS) with other technologies such as Mobile App (MA) and Unmanned Aerial Vehicle (UAV) and with different point cloud extraction techniques (structure from motion, 3D point clouds) in the assessment of canopy size parameters such as thickness, height and volume. Therefore, the study aimed to evaluate, compare, and cross-validate the potential and limitations of different technologies to assess the vine canopy size parameters (thickness, height, volume) by processing 3D point clouds. Three trials were carried out to test the different tools in a vineyard. Each test was made of a UAV flight, an MLS scanning over the vineyard and a MA acquisition over 48 geo-referenced vines. The Leaf Area Index (LAI) were also assessed and taken as reference value. The results showed that the analysed tools were able to correctly discriminate between zones with different canopy size characteristics. In particular, the R^2 between the canopy volumes acquired with the different tools was higher than 0.7, being the highest value of R^2 = 0.78 with a RMSE = 0.057 m^3 for the UAV vs. MLS comparison. The highest correlations were found between the height data, being the highest value of R^2 = 0.86 with a RMSE = 0.105 m for the MA vs. MLS comparison. For the thickness data, the correlations were weaker, being the lowest value of R^2 = 0.48 with a RMSE = 0.052 m for the UAV vs. MLS comparison. The correlation between the LAI and the canopy volumes was moderately strong for all the tools with the highest value of R^2 = 0.74 for the LAI vs. MLS data and the lowest value of R^2 = 0.69 for the LAI vs. UAV data. Based on these results, all tools analysed can correctly assess different canopy size characteristics. In particular, the MLS combines good estimation of canopy size characteristics with good usability, being an embedded solution.

5 Can a Variable-Rate Sprayer Be Efficient and Economic, Testing and Economic Analysis in Viticulture

The final step of this work has been the integration of VRA kit into one of the most used pneumatic sprayers (Martignani M612 Whirlwind) in Tuscany viticulture and tested to verify the spraying performance of the system and to analyse its economic performance over an entire crop protection season. To convert the conventional sprayer into a VRA sprayer, the ultrasonic sensors (NORAC Topcon) described in the previous chapter were installed at the forepart of the sprayer. In addition, the original valves were replaced by electronic valves controlled by the US. At the rear of the sprayer there were eight electric valves, four on each side. Each valve controls a range of flow rates, adjusting the pressure from 1 to 2 bar. When the flow rate of a valve is not enough, it's closed and the subsequential in terms of flow rate is opened to provide the required flow rate. To assess spray performance, three trials were conducted in a vineyard using a profile sampling strategy (BS ISO 22522:2007). Normalised deposition and spray coverage were extracted from artificial targets using spectrophotometry and image analysis techniques respectively. In addition, the economic performance of the VRA sprayer was compared with the UA sprayer for a full growing season in two plots. Normalised deposition results showed differences between detection heights (H1, H2, H3, H4) rather than between modes (VRA vs. UA). Therefore, the efficacy of VRA and UA was confirmed due to similar deposition values. The same trend was seen in the spray coverage results, although UA spray coverage was higher than VRA, usually exceeding the overspray threshold. In terms of economic performance, the study highlighted an average volume saving of 35% for VRA, ranging from 76% in the first session to 10% in the last. The resulting economic savings were €2,599.50, consisting of €2,502.5 in pesticides, €52.14 in water and €44.86 in fuel. Overall, the VRA system showed good spraying performance with a significant reduction in spray volumes. These savings had an impact on both the economic analysis, with a break-even point around the 4th year, and on the environmental sustainability of the crop protection stages, with a reduction in pesticide consumption.



6 Final Remarks

New technologies and digitalisation are paving the way for reducing the environmental footprint without compromising the economic sustainability of farms. In viticulture, one of the largest footprint operations is the crop protection phase. This scenario is the basis of my PhD path, specifically, the objectives of my PhD were to investigate the strengths and weaknesses of new sensors, technologies and techniques in canopy characterisation. In particular, the ultrasonic sensor used ensures a level of originality and innovation compared to other technologies because, unlike the first generation of US which measured the distance between sensor and target and then calculated an approximate canopy volume, this new ultrasonic sensor can directly estimate the canopy characteristics by measuring the number and intensity of echoes. These preliminary studies were fundamental for the development and calibration of a VRA kit, based on a new ultrasonic sensor, to be implemented in existing sprayers to improve the economic and environmental sustainability of crop protection.