Automated crop monitoring solutions to assess the blooming charge in orchards: preliminary results achieved by a prototype mobile lab used on apple trees

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Abstract. The paper presents and discusses the use of a mobile lab (ByeLab) equipped with optical sensors (OptRx™ and LiDAR), GNSS-RTK system and an Inertial Measurement Unit (IMU), to carry out a site-specific bloom charge assessment in apple trees. The collected data are firstly synchronized by a LabView software and then processed by dedicated algorithms in MatLab®. Preliminary investigations were performed in order to evaluate the features of the flower and leaves reflectance signature. It was observed that low NDVI values corresponded to the flowers while higher values to the leaves. It was expected that NDVI show a negative correlation with the bloom charge. Using Terrestrial Laser Scanner it was possible to validate the information about the canopy thickness collected by the LiDARs mounted on the ByeLab. The OptRx™ do not seem suitable to be applied to perform an estimation of the flower charge but, merging the data collected by the two types of sensors it is possible to build descriptive maps, which provide information about canopy thickness and vegetation index values. These can be used as reference for automating machines to be applied in thinning operations according to a site-specific approach.

Keywords: Optical sensors, Precision Farming, Ground based sensing, Vegetation Index

1. Introduction
Precision Agricultural (PA) technologies and techniques, such as: remote, proximal and ground sensing, gives many tools to decreasing the production costs and to improve the field yields. Moreover, PA aims to increase the efficiency and the sustainability of agriculture [1].

Ground remote-sensing technologies can be useful to automate several procedures which are generally carried out with techniques that require high amount of time. For example, the use of optical sensors installed on aerial or terrestrial vehicles, was assessed to provide puctual information, about the crop, such as: plants healthy status, grapevine diseases detection, canopy layout and volume and distance between plants [2,3,4].
Flower and fruit thinning are two procedures applied with the aim to improve fruit size and the annual yield apple trees. Usually the flower thinning is carried out through chemical treatments or manually by specialized staff. Chemical thinning does not take into account the variability between individual trees, but is done on a block basis. The hand-thinning is more expensive in terms of money and time spending but may be necessary if chemical thinning proves inadequate [5]. In order to carry out correctly these procedures it is fundamental estimate correctly the blooming charge. Usually this operation is done manually basing upon the personal experience of the operator and it is very complicate to measure the correct number of flowers [6]. Thus, the aim of this work is to develop an automatic system able to provide objective information about the bloom charge in apple orchard to be used as managing tool for flower thinning activities.

2. Material and methods
The experimentation was carried out to the apple orchard of “Azienda sperimentale Laimburg”, Bolzano, Italy. Two rows, with plants of *Malus domestica*, were selected. The rows are divided in several transepts trained with alternate system (figure 1): *Bibaum*, having a single trunk with two leaders and *Spindel* with single trunk leader and a circular volume; In both case the plants reach a high of 3.5 m. about.

![Figure 1. From left to right: Bibaum and Spindel training system.](image)

In order to know the real blooming charge of the investigated plants, all flowers were manually counted before starting the experimentation. The data obtained were used to validate the assessment performed by a prototype of mobile laboratory equipped with sensors developed to performed crop monitoring, during the days survey carried out in: pre-blooming, full-blooming and post-blooming in April 2018.

Preliminary investigations were performed before running ByeLab field tests in order to measure the spectral firm which characterized the component of the plant and to be compared with the Vegetation Index (VI) measures got by the optical sensors installed on the ByeLab. To this aim a portable spectrophotometer (Jaz Ocean Optics Spectrometers) was used to assess the different reflectance behavior of different plant organs (petals, corolla, flowers, leaves) and to better evaluate the features of the flower reflectance signature (figure 2). Several vegetation indexes were calculated using RED, RedEdge and NIR wavelengths values...
of the reflectance in order to define new indexes able to discriminate the flowers from the leaves. In each survey, samples of 30 flowers and leaves were analysed with the spectrophotometer.

![Jaz Ocean Optics Spectrometers and an example of leaf reflectance acquisition.](image)

**Figure 2.** The Jaz Ocean Optics Spectrometers and an example of leaf reflectance acquisition.

Through to the use of a Terrestrial Laser Scanner (TLS) (model CAM2 FARO) it was also possible to validate the information about the canopy thickness collected by the LiDARs mounted on the mobile lab. The collected raw-data were elaborated with FARO Scene 7.1.1 software (figure 3).

![Terrestrial Laser Scanner (TLS) during the scan and an example of raw data elaborated with FARO Scene 7.1.1 software.](image)

**Figure 3.** On the left the TLS during the scan and on the right an example of raw data elaborated with FARO Scene 7.1.1 software.

For the monitoring procedure the BionicYELab (ByeLab) was used (figure 4). This vehicle is an compact electric-driven tracked bins-carrier (NEO Alpin by Windegger S.r.l., Lana, Bolzano, Italy) modified with a metal structure where install the sensors and it is remote-controlled. For this experiment it was equipped with the following devices:

- three OptRx™ sensors AgLeadear;
- two LiDAR (SICK LMS111) sensors;
- an Inertial Measurement Unit (IMU) (LMRK 10 AHRS);
- a GNSS system (GEOMAX Zenith 35).
Figure 4. The ByeLab in the apple orchard during a day of surveys.

The OptRx™ devices are active optical sensors able to provide VI value calculated on the reflectance, the two LiDARs are able to detect, in a stereoscopic view, the profile of the canopy while the IMU device is useful to get data on the mobile robot orientation and to correct data collected by the previous sensors because influenced by relevant vibrations generated by terrain roughness. The collected data are firstly synchronized by a LabView® software, running on the control unit, and finally processed by dedicated algorithms in MatLab® environment. In every survey day three repetitions for each semi-canopy were carried out in order to obtain reliable data.

3. Results and discussion
The results obtained by the spectrophotometer highlight that the spectral signature of leaves and flowers (figure 5), even if collected from different plant, have similar patterns but they may have different reflectance values for the same wavelength.
In this work in addition to the most common VIs such as, Normalized Difference Vegetation Index (NDVI) and Normalized Difference Red Edge Index (NDRE), several and new VIs, were tested at the aim to find the most suitable to discriminate leaves than flowers overcoming the issue above cited. Basing to the obtained results it was possible to observe that the NDVI index is the most suitable parameter to be used to discriminate flowers from leaves.

According to the measurements done with the spectrophotometer, it is shown that NDVI index was the best for flower identification. Indeed, the lower the NDVI values, the higher the amount the flowers. Pure flowers shown NDVI values slightly negative, anyhow very near to zero, while to the leaves corresponds values plenty greater than zero. Basing on these results obtained, by the ByeLab data analysis we expect to obtain a negative correlation between the number of flowers and the NDVI value: low NDVI values in the presence of a high number of flowers and at the contrary high NDVI values with presence of a low flower charge.

Comparing the results obtained by the TLS scans processing with those from of the LiDARs, mounted on the ByeLab during the experimentation (figure 7) it is possible highlight that the system is able to obtain information about: gaps between plants, change in training system, canopy thickness, identification of small and new plants and irrigation poles. However, there is an evident stretching of the images probably due to the fact that there is a time delay in the communication between LiDAR and GPS due to difference in acquisition frequency.
Figure 7. Images obtained by TLS (above) and LiDAR (below). It is observable the stretching between the two acquisitions, the small plant and the information about the canopy.

Thanks to the algorithm elaborations it was possible to obtain descriptive maps (figure 8). These provide information about the blooming charge at three different heights of the canopy. The maps were obtained merging the LiDAR and OptRx® data. They provide information about NDVI index values, hence the number of flowers, and the canopy thickness. It was decided to associate cyan and green colors at high NDVI values, while white and yellow colors at low NDVI values. In this way low and high blooming charge were represented, respectively. Since the apple tree is a plant which blooms during the foliage stage the predominant colour in pre-blooming map is cyan. In this stage the leaves are still small and cannot be clearly sensed by the sensors. In full-blooming, since the flower is complete opened there is a predominance of white and yellow, meanwhile it is green in post-blooming because all flowers are felt done.

Figure 8. Descriptive maps associated to one scanned row: NDVI and classes thickness classes during the blooming period. From left to right: pre-blooming, full-blooming and post-blooming. The image refers to the total high of the canopy wall.

The descriptive maps shown that the NDVI trend is always low in full blooming (due to the higher amount of white provided by the flowers) if compared with ones in pre and post blooming. However, the variation trend of the NDVI index is really too scarce to set vegetative index thresholds to be used as reference to estimate the density of blooms.
4. Conclusion
According to the results obtained from ByeLab data elaborations, the used of mono-dimensional sensors, such as the OptRx™, does not seem suitable to be applied to perform an estimation of the flower charge. This is due to the low resolution which characterized them: their output refers to an average value of a scanned surface. Two-dimensional scans, for example a pixel matrix, such as multi-cameras, should be used to overcome the problem of low resolution.

Thanks to the combination of LIDAR and OptRx™ data it is possible to provide useful descriptive maps which can be suitable to be used as reference for automatic activation of machines (sprayers) and pruning activities.

In the further studies, Authors will be increased the number of optical sensors per side in order to obtained more reliable results. Beside this, new interpretative algorithms will be developed for the automatic bloom charge assessment.

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