ESTIMATING TREE HEIGHT USING LOW-COST UAV

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ABSTRACT:

Precision agriculture (PA) is defined as an agricultural management based on the observation, measurement, and response of a set of quantitative and qualitative variables that affects agricultural production. The first step in the approach to precision agriculture is, therefore, the acquisition and collection of data from optical, multispectral, geophysical sensors, etc. aimed at obtaining knowledge and monitoring of the crop. In recent years UAVs are assuming an important role in precision agriculture. The possibility of mounting RGB, multispectral, LiDAR sensors on them make these systems fast, accurate, and usability compared other geomatic methods. In this study, we focus on a very low-cost UAV system to assess individual tree height and generate 3D Model and orthophoto of the study area. We used the DJI Mini2, a low-cost UAV that can be used without a flight rating and without restrictions due to its light weight of only 250 grams. The case study where the survey was performed is an agricultural area of about 1 hectare, where are some fruit trees and a small vineyard. The area was selected because it contained both tall and small trees. The study concerned the influence of the relative flight altitude and therefore of the GSD of the images on the extraction of the dimensional data of the trees. From the results obtained, it can be stated that the flight altitude has certainly more influence on the measurement of small tree (around one meter tall) compared to tall ones (around 4 m).

1. INTRODUCTION

Precision agriculture (PA) is defined as an agricultural management based on the observation, measurement, and response of a set of quantitative and qualitative variables that affects agricultural production (Ammoniaci, 2021). The first step in the approach to precision agriculture is, therefore, the acquisition and collection of data from optical, multispectral, geophysical sensors, etc. aimed at obtaining knowledge and monitoring of the crop (Pagliai, 2022).

Precision agriculture (PA) is a relatively new discipline that was developed in the middle of the 1980s, and that has been listed among the top ten developments in agriculture in the last decades (Crookston, 2006).

PA includes a wide range of techniques and methodologies for the management and monitoring of agriculture which aim to develop an increasingly sustainable agriculture.

The increase in the world population has led the FAO to estimate an increase in the need for products and food needs of 60% compared to the annual average analysed from 2005 to 2007, in relation to the growth forecast of the world population established at around 9 billion by the year 2050 (Alexandratos, 2012). The Commission for Agriculture and Rural Development of the European Parliament has also provided the same estimate regarding the increase in the world population, underlining how the demand for healthy food and optimal nutrition constitutes one of the major future challenges worldwide. The new challenge for agriculture will consequently be to produce more in a more sustainable way. A challenge that presupposes a key concept for agriculture, namely innovation.

The geomatics techniques then become a tool of considerable importance to contribute to this challenge, just remember in the early 1990s the first agriculture machines with on-board GNSS receivers spread to map production yields and satellite images were used to discriminate areas with different soil characteristics (Casa, 2018). In addition to these methodologies, the first optical sensors were used, mounted on agricultural machines to monitor the vegetative vigour (Casa, 2018). In the early 2000s, the new major players in precision agriculture were drones, which made it possible to provide, at low cost, very high-resolution images both in the visible and in the multispectral, becoming decision support systems in the prevention of diseases and water stress and in the determination of some tree parameters (Hobart, 2020).

Usually, the UAV’s are developed with an automated drone system with sensors and cameras in order to monitor the condition and height of the crops (Velusamy, 2022).

The role of UAV is taken care by the captured images. The images can be RGB or multispectral so to help the farmers to take appropriate measures at the right time to protect the crops from diseases.

The advantage of using UAVs is certainly related to fast performance, high resolution and low cost compared to other geomatic methods (Zhang, 2021).

Among the data that are required in precision agriculture and that find an answer in the use of UAVs, are the determination of the width of the canopy and the height of the plants. In particular, the height of the plants is important for assessing the economic value of the plant and its health condition (Krause; Vaglio Laurin, 2019). The classic methods used to determine plant heights are not suitable for large-scale use (Dempewolf, 2017).

The use of multimages UAV photogrammetry with the Structure from Motion (SfM) approach allows to reduce costs and acquisition times by producing images and 3D models that allow the extraction of accurate metric information. There are various research that, in recent years, are testing the potential of UAVs for measuring the size of plants and their growth.

In (Kameyama, 2020) the research aimed to study the effects of the flight and shooting conditions of a UAV on the accuracy of the height and volume measurement of trees.

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In (Alin, 2017) a low-cost UAV was used to obtain the canopy height model, by extracting the digital surface model from the digital terrain model, and filtered it locally based on the pixel-based window size using the provided algorithm.
In this study, we focus on a very low-cost UAV system to assess individual tree height and generate 3d Model and orthophoto of the study area. We used the DJI Mini2, a low-cost UAV that can be used without a flight rating and without restrictions due to its light weight of only 250 grams.
The case study where the survey was performed is an agricultural area of about 1 hectare, where are some fruit trees and a small vineyard. The area was selected because it contained both tall and small trees.

2. MATERIALS AND METHODS

The aim of this research was to evaluate whether the use of a very low-cost UAV can contribute to providing useful parameters for precision agriculture.
For this purpose, a low-cost and open category drone was used, i.e. usable without particular requests for piloting qualifications. This was the DJI Mini 2, a quadcopter weighing less than 250 grams. The research involved agricultural land planted in part with fruit trees, with an average height of about 4 meters, and a vineyard with vines with an average height of about 1.3 m.
To this end, 3 flights were performed at different relative flight heights: 30 m, 50 m and 80 m, as we wanted to study the accuracy of the measurements with such a low-cost instrumentation as well as the influence of the relative flight altitude and therefore of the resolution of the images in determining the trees heights.
The validation of the measurements was performed with the measurements of the trees height obtained with classical topographic methodology using a total station.

2.1 Case study

The area used as a case study is in the countryside of Furtei (Sardinia - Italy). It is an agricultural land of approximately 1.2 ha, within which there are 23 plants, mainly olive and fruit trees, arranged along the edges of the land. At the center of the area there is a vineyard made up of 5 rows of about 80 m long each. In figure 1 the area on which the experimentation was carried out.

Figure 1. Case study

2.2 UAV survey

A DJI quadcopter, the MINI 2, was used for the research. The main feature of this drone, in addition to its low cost, is its weight, which is less than 250 grams; it is classified as a light UAV, low-cost and easy to use.
The technical specifications guarantee a maximum battery life of 30 minutes and a wind resistance of 29-38 km/h. The small quadcopter supports HD video transmissions up to 10 km thanks to the OcuSync 2.0 video transmission system which gives greater safety in flight. The DJI Mini2 (figure 2) is equipped with a GNSS satellite positioning system and a digital camera with a 3-axis stabilizer, with an inclination of -90°. The digital camera allows to make 4k 30fps videos and 12MP images thanks to a 1/2.3" CMOS sensor with a pixel size of 1.5 mm and a lens with an f/2.8 aperture.

Figure 2: DJI Mini2

In the research, 3 flights were carried out at different flight relative quote: 30 m, 50 m and 80 m, with the aim of studying the influence of the flight quote on the data collected. Table 1 shows the flight parameters of the 3 measurements.

	Flight 1	Flight 2	Flight 3
Relative quote	30 m	50 m	80 m
Overlap	80%		
Sidelap	40%		
GSD	1.03 cm	1,72 cm	2,75 cm
Flight time	3' 48''	2' 03''	1' 16''
Max velocity	11 km/h	12 km/h	15 km/h
n. images	83	27	8
n. flight lines	4	2	1

Table 1. UAV Flight Parameters

As can be seen from table 1, as the flight relative quote increased, the number of images decreased but at the same time the Ground Sample Distance (GSD) increased. We went from 83 images for the 30 m flight to only 8 images for the 80 m flight, while the GSD went from 10.3 cm for the 30 m flight to 2.75 cm for the 80 m flight. Having flights with few images means reducing both acquisition and processing times.

The flights were carried out in August 2022 on a windless day to ensure the stability of the UAV.
In order to georeference the point clouds, 10 Ground Control Points (GCPs) distributed throughout the agricultural area were used. For their arrangement the prescriptions of (Santos Santana, 2021) were followed. In figure 3 the disposition of the GCPs.
Another 4 points were materialized and measured on the ground and used as Check Points (CPS).

Figure 3. GCPs position

The GCPs and the CPs were materialized on the ground through red and white circular targets of 20 cm in diameter (figure 4). The shape and size of the targets have been planning to be visible on images acquired from a height of about 80 m. The points were surveyed using a GNSS receiver in RTK mode, with the ITALPOS Permanent Stations Network, determining their coordinates in the ETRF2000 datum with geodetic height.

Figure 4. Target

The images from 3 surveys were processed using the Metashape by Agisoft software, that implements the Structure from Motion (SfM) algorithm. The SfM is a low-cost photogrammetric method for high-resolution topographic reconstructions. The SfM operates under the same basic tenets of the stereoscopic photogrammetry. However, they fundamentally differ because in SfM the geometry of the scene, camera positions and orientation are solved automatically without points known. In the other method, instead, points are solved simultaneously using a highly redundant, iterative bundle adjustment procedure, based on a database of features automatically extracted from a set of multiple images with a high degree of overlap (Szeliski, 2010).
The Metashape workflows consist in the following main steps: image import, image alignment, generation of the sparse point cloud, optimization of image alignment, georeferenced, generation of the dense point cloud, generation DEM and generation orthophoto (Vacca, 2018; Giannattasio, 2013).

2.3 Trees height measurements

All the plants were measured with classic geomatic methods, in particular the plants over 1 m in height were measured with the Total Station, while the smaller ones were measured with a metric pole (figure 5).

Figure 5. Tree height measurements

The measurements were used to validate the heights extracted from the UAV surveys.

3. RESULTS

The images of the 3 flights were processed with the Metashape by Agisoft software. The processing of the dense cloud points of the 3 flights was performed with High quality parameter. The dense point clouds were georeferenced using 10 GCPs, while 4 are the CPs. Table 2 shows the Root Mean Square (r.m.s.), in centimeters, on the GCPs and CPs for the 3 flights.

	30 m (cm)			50 m (cm)			80 m (cm)		
	E	N	Q	E	N	Q	E	N	Q
r.m.s GCPs	1.2	1.1	0.5	0.5	0.5	1.1	0.2	0.2	0.1
r.m.s CPs	2.3	1.7	2.0	1.0	1.4	5.0	0.6	2.2	4.0

Table 2. GCPs and CPs r.m.s.

Figures 5, 6 and 7 show the values of the r.m.s. over the GCPs.

Figure 6. r.m.s. GCPs – 30 m flight

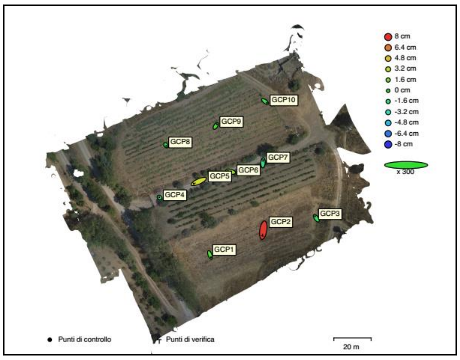

Figure 7. r.m.s. GCPs – 50 m flight

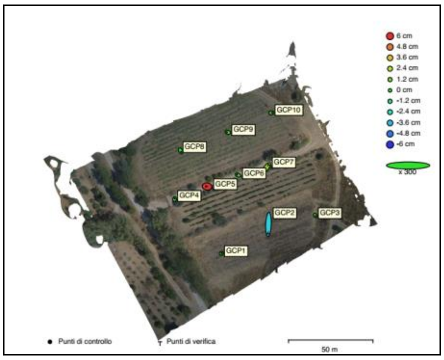

Figure 8. r.m.s. GCPs – 80 m flight

Table 3 reports the number of points in the dense point cloud for each flight and the size of the corresponding file.

	30 m	50 m	80 m
N. points	191.032.802	65.456.200	24.695.518
File Size	2.68 GB	1.10 GB	421 MB

Table 3. N. points and dimension of the dense point cloud

The figures 8, 9 and 10 show the dense point cloud for each flight.

Figure 9. Dense Point cloud – 30 m

Figure 10. Dense point cloud - 50 m

Figure 11. Dense Point Cloud - 80 m

For each flight the mesh and orthophotograph were also produced.

3.1 Trees height measurement

After processing the dense point clouds, the heights of the plants were extracted from them. This operation has required particular attention as, for each plant, both the height of the land and the height of the highest part of the plant had to be determined. The measurements were made within the Metashape software with the help of some of its tools.
To identify the points of interest in the dense cloud, we initially highlighted the crown of the plant using the "circular selection" command, then the highest altitude point among the selected points of the crown was extracted.

Figure 12 shows the procedure followed.

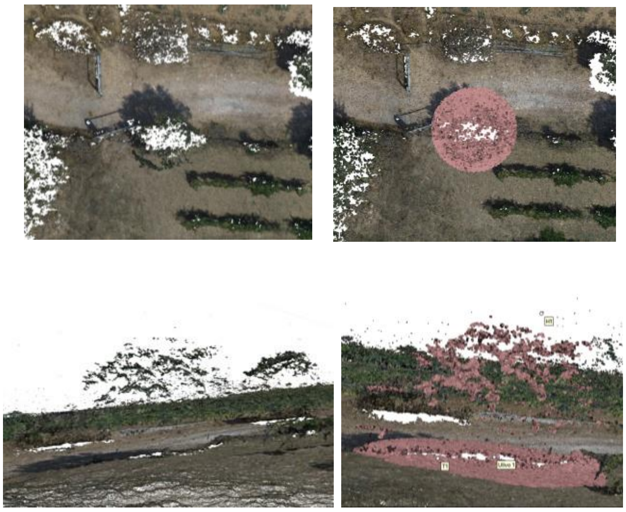

Figure 12. Tree height measurement

The tree hight was therefore estimated from the difference between the height of the trees and the height of the ground.
After determining the height of all the trees, these were compared with direct measurements. Table 4 shows the statistical results of these differences, while figure 13 shows the normal distribution of the differences.

	30 m	50 m	80 m
media (m)	0.276	0.256	0.091
r.m.s. (m)	0.391	0.372	0.326

Table 4. Statistical results of trees

	30 m	50 m	80 m
media (m)	0.112	0.214	0.253
r.m.s. (m)	0.08	0.183	0.198

Table 5. Statistical results of vines

	30 m	50 m	80 m
media (m)	0.228	0.244	0.137
r.m.s. (m)	0.334	0.366	0.325

Table 6. Statistical results of trees+vines

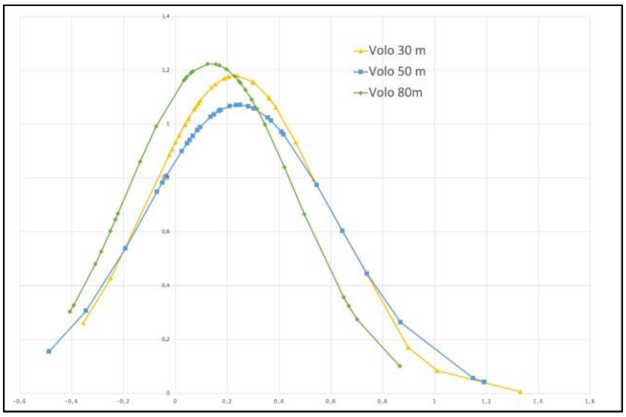

Figure 13. Normal distribution of differences

4. DISCUSSION

The research involved the use of a low-cost UAV for determining the heights of trees and vines. In particular, the study concerned the influence of the flight relative quote and therefore of the GSD of the images on the extraction of trees metrical parameters.
From the results obtained it would seem that the flight relative quote does not decisively influence the measurement of the height of tall trees. The flight at 80 m would seem to give better results with a rms of 33 cm compared to 39 cm of the flight at 30 m. For small trees, such as vines, flying at lower relative quote returns better values. For 30 m flight the rms is 8 cm, for 50 m flight it is 18 cm, and for 80 m flight it is 20 cm.
Considering the set of tall and small plants, the rms of the differences are 33 cm for the flight at 30 m, 37 cm for the flight at 50 m and 32 cm for the flight at 80 m.
We can therefore say that the influence of the flight altitude is certainly more incident in the measure of small plants (around the meter) than the high ones (around 4 m).

5. CONCLUSION

The research had the objective of studying the potential and accuracy of a very low-cost drone for measuring the heights of trees. The possibility of using this methodology, as an alternative to the normal measurement procedures, puts us in front of interesting scenarios. The procedure performed would allow overcoming the limits associated with traditional geomatic measurement techniques which are more slow and costly both in terms of time and man-hours.
The results obtained are comforting and in line with those obtained from other research, further improvements can certainly be obtained by integrating nadiral flights UAV with oblique flights UAV. This would allow to obtain more complete point clouds of the foliage avoiding holes and thus improving the process of calculating heights.

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