glasnik zaštite bilja 65 godine

Peter Berk[1], Matej Sečnik[2], Andreja Urbanek Krajnc[1], Denis Stajnko[1] Original scientific paper

Digital evaluation of the leaf wall area of the grapevine (*Vitis vinifera* cv. Sauvignon) by using LIDAR measuring technology

Abstract

A dosage rate reduction of plant protection products mixed with water, i.e. spray mixture, in a prescribed concentration in the vineyard will only be possible in the future, if the natural characteristics of vine canopy structures (leaf wall area) and canopy management are taken into account. In a practical experiment in the vineyard we evaluated the leaf wall area of the vine cv. Sauvignon on different segments on the left and right side of the vine canopy. We compared the results of manual measurements and laser measuring technology (LIDAR) with the corresponding algorithm, with which we enabled the digital reconstruction of the leaf wall area of the vine. The manual measurement of the leaf wall area was carried out using an automated image analyser. The digital system for measuring the leaf wall area on different segments consisted of a LIDAR sensor and a Differential Global Positioning System (hereinafter DGPS). To determine the exact DGPS position of the LIDAR sensor during the measurement, we set up a DGPS base station. Using the Excel software (CORREL function), we estimated the relationship between the dependent variable (digital number of points in the cloud) and an independent variable (leaf wall area, manually measured). An analysis of six randomly selected vines in the vineyard revealed the maximum value of the correlation coefficient r = 0.80 for the left side and r = 0.90 for the right side of the leaf wall area of the vine, respectively. In the near future the virtual three-dimensional space will provide more even control of spray mixture over the entire structure of the leaf wall area in the vineyard based on autonomous decision-making models.
Keywords: *plant protection, leaf wall area, grapevine canopy structure, LIDAR sensor, navigation system, precision viticulture*

Introduction

Precision viticulture (PV) is relatively new discipline, which development and research work started in the 1990s (Santesteban, 2019). PV aims to optimize the implementation of viticulture processes in order to increase its economic and environmental sustainability. Despite the rapid growth of PV in the last two decades all around the world, there is little PV research work about its benefits potential for advanced analytics based on real-time data capture.

For good quality and yield of crop (grapes) in the vineyard, it is necessary to ensure adequate protection of the crop against various diseases, pests and weeds. Crop protection can be carried out in several different ways, the most important of which is chemical protection. In protecting the crop against harmful organisms with various liquid plant protection products (hereinafter PPP), part of PPP residues remains on the crop, while the other part finds its way to the surrounding area leading to contamination of soil, groundwater, air, plants and animals, which is a major problem in modern viticulture. Regrettably, this cannot be solved overnight, by returning to the traditional way of farming by avoiding the use of PPPs. Therefore, for stable and sustainable grape production, it is necessary to ensure the reduction of harmful effects on the environment in which we live. The modern method of viticulture production will thus be the application of smaller quantities of PPPs, given the fact that we will have to maintain the same quality of grape protection in the vineyard. However, the automated PPPs process must

[1] dr. sc. Peter Berk, prof. dr. sc. Andreja Urbanek Krajnc, prof. dr. sc. Denis Stajnko,
University of Maribor, Faculty of Agriculture and Life Sciences, Pivola 10, 2311 Hoče, Slovenia
[2] Matej SEČNIK, Department of Energy Engineering, Faculty of Mechanical Engineering, Aškerčeva 6, 1000 Ljubljana, Slovenia
Corresponding author: denis.stajnko@um.si

be able taking into account the tree canopy structure and modern management, evaluated in real-time conditions throughout advanced modular measuring system.

The development and expansion of digitalization on the grape production farms requires the development of new viticultural practices in PV relating to the precise process of measuring the various developmental stages of the Leaf wall area (hereinafter LWA) in vineyards. The increase of doses of PPPs in vineyards needs accurate knowledge on the vine canopy characteristics (egs. variety, vigor, canopy management, canopy structure, plant height, leaf area, phenological phase, plant age), which are the most important factor in improving the application of PPPs for optimal quality of grapes (Klodt et al., 2015). The Leaf wall area (hereinafter LWA) can be measured manually, which is a destructive, time-consuming and expensive procedure because all leaves must be plucked from an individual vine canopy by hand. The characterization of grapevine development in case of a large number of cultivars (viticulture) or breeding material (grapevine breeding) requires simple, fast and sensor-based modular systems which are applicable from a driving fruit-growing vineyard tractor for high throughput data acquisition (Herzog et al., 2014).

As the evaluation of the natural properties of the vine canopy is a very complex task, individual research groups started planning indirect and non-invasive measurement systems twenty years ago. Systems have been studied to characterize grapevine foliage directly in vineyards (Mabrouk and Sinoquet, 1998; Diago et al., 2012; Arnó et al., 2013). Most of the researches based on sensor techniques, such as electromagnetic scanners (Berk et al., 2016), ultrasonic sensors (Stajnko et al., 2012), laser scanners (Berk et al., 2020), infrared sensors (Bates et al., 2011), fish-eye optical sensors (Bates et al., 2011; Johnson and Pierce, 2004) or model based strategies (Louarn et al., 2008, Stajnko et al., 2012; Molto et al., 2001; Berk et al., 2016). However, only a few studies reported on automated approaches for monitoring grapevine growth habits directly in vineyards using low-cost consumer cameras (Roscher et al., 2014).

Laser measuring technology working on the principle of the LIDAR method for measuring the distance from the target based on laser beams enables modelling two-dimensional or three-dimensional geometric shapes of objects. For experiments in an orchard, vineyard or laboratory, the measurement data are processed in real-time, which is a great advantage of the measurement system, (Sanz et al., 2011). The laser measuring sensor most commonly applied in precision agriculture uses the pulse time method. This method works by measuring the time interval between the emitted (pulse) and detected laser beam by the sensor on the receiving unit, which determines the distance between the sensor and the object. The use of a laser measuring system with associated algorithms enables the reconstruction of three-dimensional evaluation of LWA and natural vine canopy shapes on more efficient way than any other measurement system.

Our research work presents a novel developed measurement system for non-invasive, fast and objective LWA evaluation on different vine canopy segments. Automated modular measurement system in real-time enables capturing and storaging the digital measurements throughout laser LMS111 sensor.

The main aim of our research work are presented with the follow hypotheses:

- to perform LIDAR leaf wall area measurements,
- to perform manual measurements of leaf wall area using manual leaf removal and scanning in different vine canopy heights,
- to develop an algorithm for evaluation and reconstruction of vine canopy properties (leaf wall area) and
- to estimate the relation between manual leaf area measurements and digital LIDAR vine canopy measurements.

Materials and methods

The research work included two of techniques for the leaf area estimation. First, we applied automated laser LIDAR measuring technology using laser beams to capture the green LWA on the vine canopy (Figure 1). In the second part of the field experiment, we manually plucked all leaves from six individual vine canopies in the vineyard, which were used for determining their dry mass and area in the laboratory.

Vineyard

For experimental purposes, we used the vineyard of the agricultural farm Vinko Šerbinek located in Plač, northeaster Slovenia. The size of the experiment area was 2000 m^2, the GIS location of vineyard was 46°40'10.2" N, 15°35'57.7" E. Vines of cultivar 'Sauvignon' grafted on Kober 5BB rootstock are growing in an intensive 16-year old vineyard plantation with 2.3 m x 0.85 m spacing. The height of vine stocks steam was 0.7 m and plants were fixed in vertical trellis and trained according to standard unilateral Guyot with single-spawning (spar with up to ten buds) with a plug (one to two buds on the plug). In the experiment for the evaluation the LWA the vines were in BBCH91 phenological phase of growth (Lorenz et al., 1995).

Digital evaluation of LWA in a vineyard

The modular electronic measuring system for digital evaluation of the LWA in the vineyard contains three main components. The first one consists of laser (LIDAR) measuring device mounted on a special bracket on the tractor, for digitally determining the amount of LWA on an individual segment of particular vine. A laser sensor manufactured by SICK, model LMS111 was applied (Figure 1), which offers the IP67 protection standard suitable for outdoor use in the vineyard. It enables data capture with a frequency of 50 Hz and an angular resolution of 0.5 °. Its range is up to 20 m. Data transfer takes place in real-time via an Ethernet interface with a nominal speed of 100 Mbit/s.

The second component built into the modular system is a Teensy 3.6 microcontroller with an added Ethernet module, which transfers measurements from LIDAR measuring device. The Teensy 3.6 microcontroller has a 32-bit 180 MHz ARM Cortex-M4 built-in processor, which offers enough processing power to process data from LIDAR measurement device.

The third component is the DGPS measuring system allowing to determine the driving speed and location of the modular measuring system on a few centimetres accurately. The location and speed of the modular system can be determined with a frequency of 10 Hz. We used the latest DGPS system from UBLOX, the F9P receiver model. The system enables two-frequency reception of GPS signal with RTK correction. The system consists of two parts. In the field near the vineyard, we install the DGPS reference station (Figure 2), which takes care of the correction of the pseudo distances of the GPS receiver. The drawing of the GPS trajectory of movement in the vineyard on the orthophoto map was performed with the help of the QGIS (QGIS Standalone Installer Version 3.12) software package (Figure 2). The correction data is transmitted to the mobile station (mounted on the tractor) via a real-time data connection, which were later demodulated and used to correct the GPS data. By applying a user interface developed via the Teensy 3.6 microcontroller, we captured laser measurements in real time and saved them to a txt file.

Separate left and right side digital reconstruction of the vine LWA was estimated automatically with a modular measuring system mounted on ANTONIO CARRARO TRX 8400 tractor. When moving between two rows of the vineyard, we measured the real-time polar coordinates (distance, angle) from the centre of the left and right row of the vine canopy wall using reflected laser beams. The data were recorded in real time on the hard disk of the modular measuring system. A precise digital evaluation of the LWA of the vine was enabled, which we stored in a virtual digital space.

The processing of laser measurement data was performed using our own algorithm written in the Matlab R2015a software tool. Algorithm was used for displaying the digital number of hits of reflected laser beams on individual LWA segments of the vine canopy. Digital reconstruction of the LWA (covered left and right side of vines) was presented via a graphical user interface in the form of a digital number of points in the cloud (Figure 3 a, b, c). From the point cloud, we determined the number of points, individually for eight individual segments i.e. four for the left and four for the right side of the vine canopy. The individual values of the number of points in the cloud were then compared with the actual LWA, defined in the laboratory on the basis of manual measurements for each individual segment separately. For the analysis of the LWA, six vines were randomly selected in the vineyard (3 vines in the left side and 3 vines in the right side). For each individual segment of the vine LWA, we determined the number of points in the cloud.

-

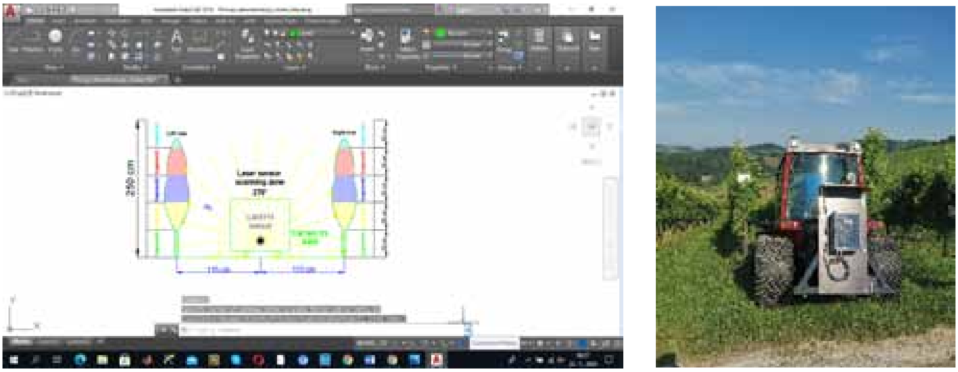


Figure 1. Principle of digital reconstruction of the vine LWA with the help of an automated modular measuring system

Slika 1. Princip digitalne rekonstrukcije područja površine listova vinove loze uz pomoć automatiziranog modularnog mjernog sustava

After performing digital measurements of the LWA of the vine, we performed manual measurements of the LWA on the same six selected vines on the left and right side separately, by dividing them into four vertical segments as follows: segment 1 (yellow) ranging from 50 cm to 100 cm, segment 2 (blue) from 100 cm to 150 cm, segment 3 (red) from 150 cm to 200 cm and segment 4 (turquoise) from 200 cm to 250 cm (Figure 1). The width of the leaf picking area was dependent of the canopy management and the distance between the vines, so it was approximately 85 cm. Each leaf was manually plucked from each individual segment of the vine canopy wall and stored in a plastic bag prior analyses (Figure 2 a). The LWA of individual vine segments was later evaluated in laboratory by scanning the leaves and measuring them with the help of Easy Leaf Area software (Department of Plant Sciences, University of California) (Figure 2 b).

The destructive LWA measurements were estimated immediately after the completion of the indirect estimates by removing all leaves at the petiole from four different segment for each sample vine. The analysis of the total LWA per segment was carried out using the "Easy leaf area" programme. Six for each vine (N=6) within both measures the fresh leaf weight (W) of each section was determined and referred to the LWA and weight of the scanned segment.

The Excel software (CORREL function) was used for statistical analysis of the linear regression estimation between the point clouds and manually measured LWA.

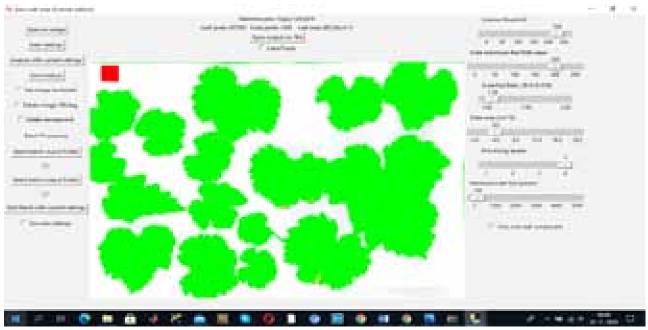
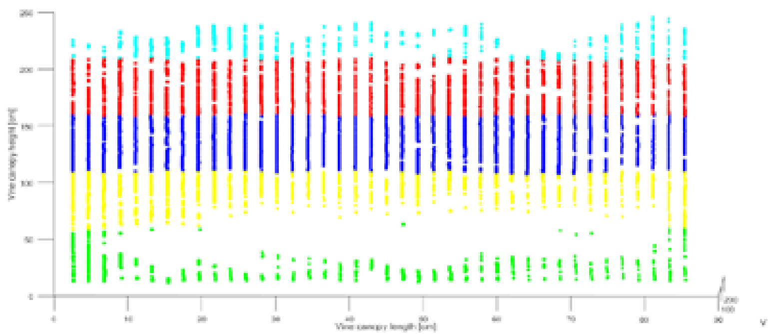
a)  b) 

Figure 2. Manual measurement of leaf wall area a) storing each leaf in a plastic bag b) leaf wall area evaluating using software programme (Easy leaf area)

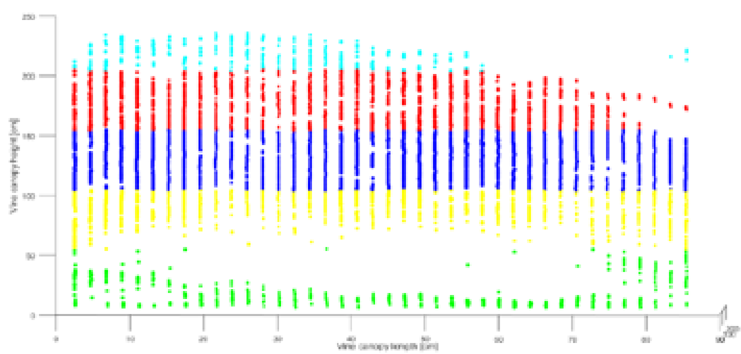
Slika 2. Ručno mjerenje površine listova a) čuvanje svakog lista u plastičnoj vrećici b) procjena površine listova pomoću softverskog programa (Easy leaf area)

Figure 3 shows a digital reconstruction of the vine LWA for the left side of three randomly selected vines. Similar digital reconstruction was made also for the right side of vines.

a)



b)



c)

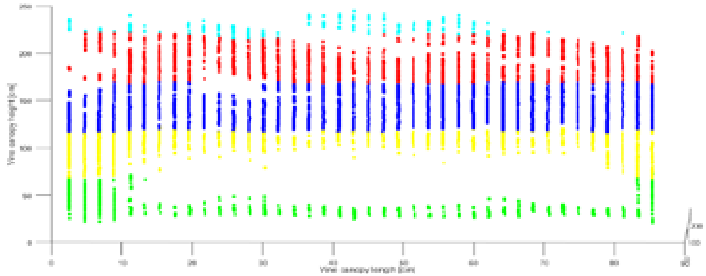


Figure 3. Digital reconstruction of three randomly selected vine LWA for the left side of the experiment: a) the first selected vine, b) the second selected vine, c) the third selected vine

Slika 3. Digitalna rekonstrukcija listne površine tri slučajno odabrane loze sa lijeve strane: a) prva odabrana loza, b) druga odabrana loza, c) treća odabrana loza

Results

Figure 4 shows a correlation results between the number of points in the cloud and the manually measured LWA on all four segments of the left (a) and right (b) side of the six vines.

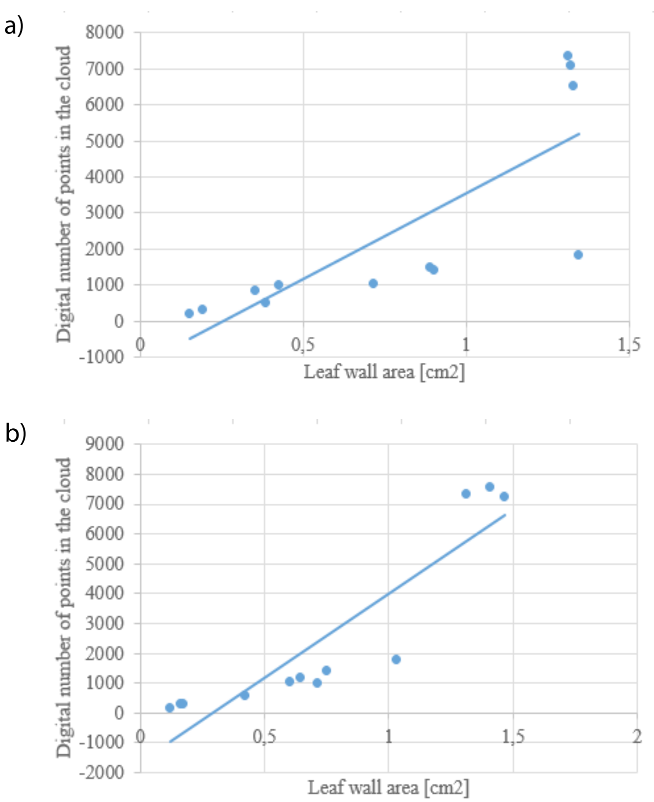


Figure 4. Correlation between the number of points in the cloud and the manually measured LWA on all four segments of the left (a) and right (b) side of the six vines

Slika 4. Korelacija između broja točaka u oblaku te ručno izmjerena površina lista za sva četiri segmenta lijeve (a) i desne (b) strane šest trsova

Pearson's correlation coefficient was applied in order to analyse the reliability of the automated measuring technique in comparison to the manual destructive leaf area mesurement procedure. We determined the correlation coefficient of r = 0.80 for the left side and r = 0.90 for the right side of three vines in the vineyard (Figure 4). From the values of the correlation coefficients, we can conclude that in our case there is a positive high correlation between the two variables. From the results we can conclude that the automated measuring technology LIDAR is comparable or even better than the solutions of other researchers. Researchers (Llorens et al., 2011) estimated the maximum value of the correlation coefficient (r_{max} = 0.409) between the number of reflected laser beams and the LWA. The proposed automated measuring technology was proven to be very appropriate to improve the crop management processes and the efficiency of pesticide applications.

Conclusions and discussion

The research work describes the precise measuring system LIDAR, which defined the LWA on individual segments of the vine canopy in the vineyard and is part of an automated modular measuring system for digital reconstruction of the particular vines. Algorithm for displaying the digital number of hits of reflected laser beams on individual LWA segments of the vine canopy performed based on a stand-alone algorithm developed in the Matlab R2015a software package. With the digital reconstruction of the vine, we enabled the analysis of the natural properties of the canopy accurately, proving by the high positive correlation between the digital number of point clouds on four individual segments of the canopy and the manually measured LWA.

Without a doubt, optical measuring systems including a laser measuring sensor for electronically identify the vine canopy provide the most accurate and detailed information on the structure of the natural shape of the vine canopy in the vineyard. With the appropriate algorithm, we can control the operation of the optical measuring system and create a virtual environment at low cost by installing the measuring system on a tractor. For all the above reasons, optical measuring systems installed on a tractor and in the near future on sprayer prototype will be enabled automated spraying application process in permanent vineyards. We believe that in the near future the virtual three-dimensional space will provide more even control of spray mixture over the entire structure of the LWA in the vineyard based on autonomous decision-making models. Information in the form of the estimated size of the LWA on the individual segment of the vine canopy in the vineyard will be included in an autonomous decision-making model with which we will be able to optimize the PPP mixture rate in relation to the vine leaf wall area.

Acknowledgements

The authors acknowledge the Ministry of Agriculture, Forestry and Food for granting EIP project No. 33117-3002/2018. Authors acknowledge the Chamber of Agriculture and Forestry of Slovenia - Agricultural and Forestry Institute Maribor (Simona Hauptman, Roman Štabuc) for technical support in carrying out experiments. Authors also acknowledge the Public Scholarship, Development, Disability and Maintenance Fund of the Republic of Slovenia for granting the PKP project No. 041103-4-FKBV3.

References

Bates, T., Grochalsky, B., Nuske, S. (2011) Automating measurements of canopy and fruit to map crop load in commercial vineyards. *Res Focus: Cornell Viticulture Enology* 4 1-6.

Berk, P., Stajnko, D., Belšak, A. Hočevar, M. (2020) Digital evaluation of leaf area of an individual tree canopy in the apple orchard using the LIDAR measurement system. *Computers and electronics in agriculture* 169 1-12.

Berk, P. (2018) *Defining plant protection product dose rate using a fuzzy decision-making model*. Doctoral thesis. University of Maribor, Faculty of Mechanical Engineering, Slovenia.

Berk, P., Hočevar, M., Stajnko, D., Belšak, A. (2016) Development of alternative plant protection product application techniques in orchards, based on measurement sensing systems: A review. *Computers and electronics in agriculture* 124 273-288.

Diago, M.P., Correa, C., Millán, B., Barreiro, P., Valero, C., Tardaguila, J. (2012) Grapevine yield and leaf area estimation using supervised classification methodology on rgb images taken under field conditions. *Sensors* 12(12) 16988-17006.

Fiorani, F., Schurr, U. (2013) Future scenarios for plant phenotyping. *Annu Rev Plant Biol*. 64 267-91.

Herzog, K., Roscher, R., Wieland, M., Kicherer, A., Läbe, T. Förstner, W. (2014) Initial steps for high-throughput phenotyping in vineyards. *Vitis* 53(1) 1-8.

Johnson, L.F., Pierce, L.L. (2004) Indirect measurement of leaf area index in california north coast vineyards. *HortScience* 39(2) 236-38.

Klodt, M., Herzog, K., Töpfer, R., Cremers, D. (2015) Field phenotyping of grapevine growth using dense stereo reconstruction. *BMC Bioinformatics* 1-11.

Llorens, J., Gil, E., Llop, J., Escolà, A. (2011) Ultrasonic and LIDAR Sensors for Electronic Canopy Characterization in Vineyards: Advances to Improve Pesticide Application Methods. *Sensors* 11(2) 2177-2194.

Lorenz, D.H., Eichhorn, K.W., Bleiholder, H., Klose, R., Meier, U., Weber, E. (1995) Growth stages of the grapevine: Phenological growth stages of the grapevine (vitis vinifera l. ssp. vinifera)-codes and descriptions according to the extended bbch scale. *Aust J Grape Wine Res*. 1(2) 100-3.

Louarn, G., Lecoeur, J., Lebon, E. (2008) A three-dimensional statistical reconstruction model of grapevine (vitis vinifera) simulating canopy structure variability within and between cultivar/training system pairs. *Ann Bot.* 101(8) 1167-84.

Mabrouk, H., Sinoquet, H. (1998) Indices of light microclimate and canopy structure of grapevines determined by 3d digitising and image analysis, and their relationship to grape quality. *Aust J Grape Wine Res*. 4(1) 2-13.

Molto, E., Martin, B., Gutierrez, A. (2001) Pesticide loss reduction by automatic adaptation of spraying on globular trees. *Journal of Agric. Eng. Res.* 78 35-41.

Roscher, R., Herzog, K., Kunkel, A., Kicherer, A., Töpfer, R., Förstner, W. (2014) Automated image analysis framework for high-throughput determination of grapevine berry sizes using conditional random fields. *Comput Electronics Agric.* 100(0) 148-58.

Santesteban, L. G. (2019) Precision viticulture and advanced analytics. A short review. *Food Chemistry* 279 58-62.

Sanz, R., Llorens, J., Escolà, A., Arnó, J., Dasi, M., Vilalta, J., Camp, F., Aguilà, F.J., Solanelles, F., Planas, F.S., Pallejà, T., Palacín, J., López, J.E., Moral, I., Rosell, P. (2011) Innovative LIDAR 3D Dynamic Measurement System to Estimate Fruit-Tree Leaf Area. *Sensors* 11 5769-5791.

Stajnko, D., Berk, P., Lešnik, M., Jejčič, V., Lakota, M., Štrancar, A., Hočevar, M., Rakun, J. (2012) Programmable ultrasonic sensing system for targeted spraying in orchards. *Sensors* 12(11) 15500-15519.

Prispjelo/Received: 28.5.2021. Prihvaćeno/Accepted: 5.7.2021.

Izvorni znanstveni rad

Digitalna procjena lisne površine krošnje stijenke vinove loze (Vitis vinifera cv. Sauvignon) korištenjem LIDAR mjerne tehnologije

Sažetak

Smanjenje količine utroška sredstava za zaštitu bilja i same smjese za prskanje u budućnosti će biti moguće samo ako se uzmu u obzir prirodne karakteristike krošnje vinove loze tj. lisne površine krošnje trsa. U praktičnom pokusu u vinogradu procijenjena je lisna površinu krošnje vinove loze cv. Sauvignon na različitim segmentima s lijeve i desne strane krošnje uz pomoć ručnih mjerenja i laserske mjerne tehnologije (LIDAR). Dobiveni rezultati uspoređeni su s pripadajućim algoritmom čime je dobivena digitalna rekonstrukcija lisne površine vinove loze. Ručno mjerenje površine listova provedeno je u laboratoriju pomoću digitalnog lisnog skenera nakon što je lišće ručno pobrano s trsova i dopremljeno u sam laboratorij. Digitalni sustav za mjerenje lisne površine na različitim segmentima krošnje sastojao se od LIDAR senzora i DGPS navigacijskog sustava. Da bi se odredio točan DGPS položaj LIDAR senzora tijekom mjerenja, postavljena je DGPS bazna stanica. Pomoću regresijske metode utvrđen je odnos između zavisne varijable (digitalni broj točaka u oblaku) i nezavisne varijable (površina listova izmjerena skenerom). Rezultati analize imeđu dvije uspoređivane metode na šest slučajno odabranih trsova vinove loze otkrivaju vrijednost koeficijenta korelacije r = 0,80 za lijevu i r = 0,90 za desnu stranu krošnje. U bliskoj budućnosti virtualni trodimenzionalni prostor pružit će ravnomjerniju kontrolu smjese raspršivača preko cijele strukture područja stijenke lišća u vinogradu na temelju autonomnih modela odlučivanja.

Ključne riječi: *zaštita bilja, površina lišća, struktura vinove loze, LIDAR senzor, navigacijski sustav, precizno vinogradarstvo*