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S09: ROBOTICS, MECHANIZATION AND SMART HORTICULTURE

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S09: ROBOTICS, MECHANIZATION AND SMART HORTICULTURE; BUCHAREST, EHC2024, MAY 13-16

ORAL PRESENTATIONS

SESSION I: DATA ANALYSYS, MODELLING AND DSS

S09-I-O-1

Bridging digital shadows with physiological models and field applications

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The demand for high yields and fruit quality is increasing along with world population growth, demand for healthy fresh fruit, increased labour costs, and competitive land use. Precision horticulture has emerged as an approach to meet these challenges, leveraging sensors, systems, and advanced technologies to improve field management practices.
With recent advancements in artificial intelligence, particularly deep learning models, computer vision has become a fundamental part of precision horticulture. Specifically, image and point cloud processing techniques can extract plant information with high spatial and temporal resolution. In other words, this allows the acquisition of inner tree variability of relevant phenotypic characteristics, such as leaf area, crop load, fruit size, and stress indicators. By analysing the aforementioned phenotypic traits extracted from digital shadows can increase the resolution of physiological models and response to environmental conditions. These models not only enhance the ability to predict crop status but also improve precision management strategies, such as crop load management, pruning and harvesting.
Despite the inherent challenges in validating and calibrating machine vision models under real-world field conditions, the synergy between machine vision and plant physiology offers high potential for innovation in field applications. By combining the extracted plant information with the contextual knowledge of human experts, we can bridge the gap between digital data and practical field applications. For instance, integrated sensors on semi-autonomous platforms equipped with machine vision capabilities enable autonomous monitoring and decision-making in the field, while human oversight ensures the accuracy and relevance of the insights generated.
In conclusion, this plenary session aims to explore the transformative potential of bridging digital shadows with physiological models in precision agriculture. By fostering collaboration, innovation, and knowledge exchange, we can harness the power of technology to address pressing challenges in agriculture and secure a sustainable future for food production.

Keywords: Precision horticulture, Phenotype, Point Cloud, Orchard management, Optical sensors, Digitization

S09-I-O-2

SmartGrape –preventing invasive cicada-borne grapevine diseases through drone-based imaging and plant volatile sensing

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Bois noir (BN) is a cicada-borne grapevine disease first observed to have entered Switzerland in the 1990s, now causing up to 50% loss of yield and vines in vineyards. It is associated with the phytoplasma *Candidatus* Phytoplasma solani (16SrXII-A), transferred from host plants common in vineyard ground cover, to grapevines (*Vitis vinifera*), by the planthopper *Hyalesthes obsoletus* Signoret (Hemiptera: *Cixiidae*). Diseased plants cannot be cured, and climate change-related temperature anomalies increase infection risk. In Switzerland, BN is a "regulated non-quarantine organism", a classification for “particularly dangerous plant pathogens and pests which are already widely distributed”. Because there are no options for direct control of BN, practical methods for systematic and early detection are urgently needed to support management and prevention. Such methods will also be useful in preventing other invasive cicada-borne grapevine diseases, such as the mandatory quarantine disease flavescence dorée (FD), whose emergence in BN-infected areas is threatening vineyards. The goal of the study is to develop a smart package of innovative monitoring and prevention methods. Detection approaches will use spectral imaging and sampling of plant volatiles related to BN-disease infection. The data will be combined to train machine learning models to categorize diseased vines and indicate discriminating features, and simplified automated detection strategies will be developed. The package is developed in a transdisciplinary, co-creative, step-by-step process with winegrowers, representatives of the wine industry, and governmental plant quarantine service experts. The project started in July 2023. Here, we discuss insights from the initial field season, and future plans.

Keywords: *Vitis vinifera*, bois noir, flavescence dorée, chemical ecology, field spectroscopy, remote sensing, quarantine disease, robotics, uncrewed aerial vehicles

S09-I-O-3

Algorithmic pointing of the right moment of watering

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In the domain of agricultural and horticultural practices, the management of water resources holds significant ecological implications, particularly in relation to the preservation of aquatic sources. The efficacy of sustainable irrigation practices is contingent upon the method of application, the timing, and the frequency of water application. The present study articulates two primary hypotheses: firstly, that the optimal timing for irrigation can be determined by monitoring the physiological status of the plant (specifically, whether the plant maintains turgidity) in conjunction with the combined mass of the plant and its substrate; secondly, that the precise timing for irrigation can be

calculated through the analysis of plant mass data.Utilizing a computational system to ascertain the optimal irrigation timing—specifically, immediately prior to the onset of turgor loss—resulted in a reduction of water consumption by approximately 30% compared to conventional irrigation practices. Moreover, the implementation of controlled irrigation had a discernible impact on various growth parameters of the plant, including the concentrations of chlorophyll a and b, carotenoids, as well as the levels of total and reducing sugars. Plants subjected to controlled irrigation exhibited a more compact morphology in contrast to those irrigated via traditional methods. The findings unequivocally demonstrate that the employment of a scale-based monitoring system, integrated with computational analysis, not only conserves water resources in irrigation practices but also does so without compromising the growth parameters of the plants.

Keywords: drought stress, water deficit, water use efficiency, plant adaptation, remote mass sensing, algorithmic watering

S09-I-O-4

An intelligent IoT platform as an advisory system for fruit growth

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Unpredictable daily climatic variations have a direct impact on fruit physiology and quality. For apples, this manifests in fruit-size deviations, whereas tomatoes, often split or burst during the ripening phase, leading to a vital yield drop. Automated production monitoring can enable a precise estimation of plants' needs and, therefore, an optimized management of natural resources. Current practices rely only on tools measuring external parameters, like determining water stress through soil moisture. However, a sensor connected to the plant itself would improve the assessment of its needs.
Recently developed dendrometers, designed to be placed directly on the fruit, enable continuous measurement of its diameter. Combining the dendrometers measures with the respective climate data acquired near the monitored plants could provide valuable fruit-growing insights, such as the harvest timing or the probability of the fruit deviating from regular growth. Hence, using such insights, our work aims to develop a real-time fruit monitoring tool for growers providing recommendation services and alerts for possible risks of fruit damage.
An IoT platform was developed for real-time collection, storage, and visualization of the diameter measurements and climate data. It has been designed to enable effortless and immediate deployment, requiring minimal configuration. The data transfer is done wirelessly through a LoRa network. The platform also integrates a module enabling intelligent data analysis to characterize the growing pattern and its dependency on the climate, to predict the growth evolution and the final fruit diameter, and to assess eventual deviation compared to previously established models specific for each crop. These models also consider newly acquired data to perform the prediction.

Multiple acquisitions from tomatoes growing in a greenhouse and apples in orchards have been completed using the platform. The provided tool shows the potential to help optimize crop quality and production practices.

Keywords: fruit-growth modeling, real-time recommendation, plant-based indicator, connected dendrometer, IoT, data analysis

S09-I-O-5

Spray application of Popillia japonica bio-control in vineyard: viability evaluation of entomopathogenic nematodes

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Components and working parameters of pesticide application equipment (PAE) such as nozzle type, pumping system, spray pressure, and temperature can be detrimental for entomopathogenic nematodes (EPN) used as bio-control agents, thus affecting their viability and consequently the pest control efficacy. Due to limited literature, trials were conducted to test the influence of two different PAE on Heterorhabditis bacteriophora formulation viability for controlling Popillia japonica larvae to prevent vineyards colonization. To this extent, a Heterorhabditis bacteriophora formulation was sprayed by a conventional small-boom sprayer and an uncrewed aerial spray system (UASS) used in static laboratory-controlled conditions. The conventional sprayer and UASS were operated with four and two active flat fan nozzles at 0.6 and 0.3 MPa, respectively. Due to the different spray application techniques, the volume rate was 400 l ha-1 and 105 l ha-1 for the sprayer and UASS, respectively. In both cases, suspensions of water and Heterorhabditis bacteriophora were prepared to comply with the dosage equal to 250,000 nematodes m-2. The spray mixture temperature in the tanks was recorded in different positions for the entire trial duration by using thermocouples. Directly from the nozzles, the spray mixture samples were collected at five and three timings for the sprayer and UASS, respectively. Immediately after the collection, EPN viability per each sample was assessed by microscope counting of alive and dead nematodes. Furthermore, to evaluate the pest control efficacy, batches of three larvae of Galleria mellonella were placed in a Petri dish and inoculated with the samples (5 replicates). The larvae mortality percentage was evaluated after 48 hours. The data analysis showed that, for both PAEs, the EPN viability decreases progressively from the first to the last sampling timing. Interestingly at the beginning of the trials, the nematodes mortality was close to 48% and 35% for the conventional sprayer and UASS, respectively. At the end of the trials the two PAEs reached mortality equal to 88% and 69%. Even if the nematode mortality reaches very high values, the mortality of larvae was mostly above 80%, with higher lethal effect using the conventional sprayer. Results provide first information about the influence of different PAE on nematodes viability, suggesting that the choice of the PAE and their working parameters deeply influence the viability from the beginning of spray application, already when the spray mixture is prepared.

Keywords: sustainability, pest control, biological control agent, entomopathogenic nematodes, soil spray application

S09-I-O-6

Prediction of fruit thinning efficacy with a portable Vis/NIR spectrometer

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In apple fruit production early thinning is required to produce optimal yields, quality and to reduce alternate bearing. However, the effectiveness of the thinning treatment varies each year. The aim of the study was to predict fruit drop with a handheld spectrometer after an early fruitlet thinning with plant growth regulators. In 2023, at the KOB in Southwest Germany and the Laimburg research institute in South Tyrol, Italy, two apple cultivars (‘Gala’, ‘Braeburn’) received either no thinning or thinning sprays of 6-benzyladenin, α-naphthaleneacetic acid or metamitron between 8-15 mm (BBCH71). King and target lateral fruit were scanned before and after thinning with a visible/near-infrared device and fruit growth was monitored with digital callipers. A green pigment reflectance ratio of 693/674 nm showed the best results compared to a normalized difference vegetation index or rededge to seperate fruit populations into persisiting and dropping. Receiver-operating characteristic curves showed a fruit drop prediction accuracy (area under the curve) of > 75 % for five and eight days after treatment for Laimburg and KOB, respectively. Weather conditions before, during and after the thinning applications were very different at the two trial locations. Differences in temperature and sunlight conditions most likely can explain differences in the prediction result. At both locations, metamitron thinned well and showed the best prediction results possibly due to its mode of action as a photosynthesis inhibitor.

Keywords: thinning efficacy, apple, absorption

S09-I-O-7

Comparative analysis of plant stress-reducing ventilation strategies using plant sensors and decision trees across different tomato greenhouses

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In spring and summer, tomato plants cultivated in greenhouses can experience environmental stress due to increased levels of irradiation and vapor pressure deficit during the day. On such days, increased transpiration rates deplete the plant's internal water storage pools (i.e., living cells), leading to elevated daily stress with the risk of irreversible damage to the plant or its fruits. To prevent such risky events, Belgian and Dutch greenhouse farmers are applying a specific ventilation strategy, which we dubbed the 'plant stress-reducing ventilation' strategy.
This scientifically understudied strategy, currently lacking established guidelines, is approached differently by individual greenhouse growers. A comparative analysis was

conducted involving two different Belgian tomato growers. For both growers, tomato plants (Solanum lycopersicum L.) were equipped with sap flow and stem diameter variation sensors to continuously measure the plant response during the application of the plant stress-reducing ventilation strategy. The plant response was classified and combined with data from the greenhouse climate computer to generate a decision tree using machine learning. The strategic integration of a decision tree algorithm with plant sensors proved essential in unraveling the plant stress-reducing ventilation strategy in practical settings. Additionally, it facilitated comparative analysis of the different approaches employed by the greenhouse growers.

Keywords: tomato, greenhouse climate control, machine learning, plant sensors, sap flow, stem diameter variation, plant stress-reducing ventilation strategy, solar radiation, vapor pressure deficit, plant stress

S09-I-O-8

Sensor and model based irrigation of apple trees on a deep Luvisol soil

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In the Lake Constance area, in Southwest Germany, the mean annual precipitation is 800-1000 mm. However, due to climate change the rainfall distribution during the vegetation season is changing towards long periods of either dry or wet conditions. The study investigated water relations of apple trees in sensor-based irrigation treatments and their physiological behavior. The following treatments were applied to third leaf 'Red Topaz' (Malus x domestica) in the study year 2023: a digital sensor-based method with soil water tension at threshold levels of 1) 25 kPa, 2) 50 kPa, 3) a conventional interval strategy 4) a non-irrigated control and 5) a web-based climacteric water model was post-calculated for the study season and compared to the sensor based irrigation schedule. As a result of excessive irrigation in the conventional strategy, increased new shoot growth and re-flowering was observed in autumn. On the other hand, the non-irrigated control yielded an average of 10% less fruit compared to all irrigated treatments. Irrigation scheduling based on the soil water tension threshold saved 75% of irrigation events compared to conventional irrigation while the yield did not differ from the conventional strategy. Calculations using the climacteric model showed a similar savings potential based solely on freely accessible data of usable field capacity, precipitation, evapotranspiration, and orchard parameters such as row and plant spacing. Our study revealed that irrigation based on models and sensor can reduce water input as well as ensuring normal physiological behavior of apple trees.

Keywords: high-clay, water relations, water tension, young trees

S09-I-O-9

CherryTwin: A Holistic Concept for Digital Twins in Horticulture

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Digitalization in horticulture and orchards is a challenging topic that becomes increasingly important in research. Exemplified by the use case of sweet cherry trees (Prunus avium 'Satin'), we present the “For5G” project, where a framework for the creation of digital twins for individual trees is developed. Multiple twins can be aggregated to gain detailed insights into arbitrary sized groups of trees e.g. entire orchards. Starting with a concept for data collection using a photogrammetry drone equipped with a 5G module, we present an end-to-end pipeline for digital twins. Stored in a knowledge graph database, AI was utilized for various detailed evaluation pipelines solving current problems in this domain: This includes photorealistic 3D reconstructions, automated tree skeleton extraction and fruit localization and counting. After following three sweet cherry trees over the 2023 season, we published a dataset and present an outlook of ongoing work like biomass estimation and early yield prediction. Additionally, under development is an app for end-users like farmers, researchers or breeders to visualize all aspects of the digital twins aggregated in arbitrary scale. This publication shifts the focus from detailed technical implementations of singular aspects to the big picture and combines previous project results with current plans to show the potential of digital twins in horticulture. Using real world data and realistic use-cases, a holistic concept for digital twins in horticulture is transparently displayed in a way that can be adapted to comparable use cases or similar domains.

Keywords: digital horticulture, digital twin, precision farming, digital orchard, fruit cultivation, artificial intelligence, phenotyping, knowledge graph, tree monitoring, photogrammetry, UAV, sweet cherry

S09-I-O-10

Can spectrum of led light be effective in the growth of olive seedlings?

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The olive tree is an important species among the oldest cultivated trees that are identified with immortality and long-life. There are many research topics in breeding works: classification, characterization of biodiversity, variety development, and studies on obtaining new varieties. Although crossbreeding is among the most preferred breeding

method, a long time is required for seeds of hybrid individuals to flowering and fruiting. Germinated seedlings of olive plants show long-lasting juvenility, and different interventions are applied to shorten this period. With the progress in the development of light-emitting diodes (LEDs), many studies have been conducted in recent years to understand the response of plants to these light sources. In the present study, the effects of different LED light regimes on the development of olive seedlings were investigated. In the study, red (R) (656 nm), far-red (FR) (736 nm), blue (B) (450 nm), red+blue (R+B), blue+far-red (B+F), red+far-red (R+F), red+blue+far-red (R+B+F) with white (W) light as control were used as LED light applications during seedling growth. Only red light showed differences compared to others in terms of plant height. This positive effect was also evident in terms of leaf number, stem diameter, number of nodes, plant fresh and dry weight, and root fresh and dry weight. Other LED lamps containing red light gave the same meaningful results. Lateral shoot number and length parameters were not affected by different light wavelengths. The studies for more combinations of wavelengths are continuing.

Keywords: wavelength, red light, juvenility, breeding

S09-I-O-11

A Novel 3D Gaussian Splatting Approach for Leaf Area Index Estimation of Tomato Plants

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The monitoring of plant morphological characteristics, such as the Leaf Area Index (LAI) and stem thickness, has become a key point of attention in greenhouse horticulture, as it is crucial for refining cultivation practices, optimizing resource management, and enhancing overall crop productivity. In this study, a novel method to assess the LAI of tomato plants was developed that combines the advantages of both direct and indirect LAI estimation methods. This method uses the 3D Gaussian Splatting technique, by which a soft point cloud of so-called splats is derived from 2D images of the plants under study. Through post-processing of this point cloud, various significant morphological characteristics, including the LAI, can be extracted. To validate this methodology, first, a digital setup featuring a 3D mesh of a generic plant was devised, which allowed for controllable manipulation of the LAI. Of this setup, photorealistic synthetic images were rendered and used as input into the Gaussian Splatting method. Then, following splat filtering based on position, color, size, and opacity, a 3D representation of the plant was reconstructed. For LAI quantification, the point cloud was voxelized, and the voxels were classified as either leaf or non-leaf. Through top-down summation of the leaf voxel mask, a 2D LAI map was then generated, and the average of this map provided the LAI estimate. After choosing an appropriate voxel size that preserved the morphological properties of the plant, this method yielded a deviation of less than 3% from the ground truth LAI (based on the initial 3D model). Following experiments conducted on an actual plant, our proposed approach, utilizing video captured by a smartphone camera, aligns with the destructive LAI measurement of the identical plant.

Keywords: smart horticulture; digital twin; plant growth monitoring

SESSION II: DATA ANALYSYS, MODELLING AND DSS

S09-II-O-12

Smart unexpensive automation for vertical farms

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Vertical farming is increasingly recognized for its capacity to produce fresh leafy greens on a global scale. This innovative agricultural method offers significant advantages, including reduced freshwater usage, diminished need for arable land, minimized use of harmful chemicals, and a shortened production cycle. However, it also presents specific challenges, such as the need for precise environmental control tailored to the developmental stage of each cultivar and substantial initial investments required for setting up the infrastructure. The initial costs are particularly high due to the need for advanced equipment. For instance, adjustable LEDs that can modify both the light spectrum and intensity to meet plant requirements, sophisticated fertigation systems capable of delivering multiple nutrient formulas simultaneously, and automated machinery like robotic arms are costly. These technologies, while expensive and maintenance-intensive, are crucial for addressing production-related issues effectively. The current document outlines several technological innovations devised by the Fresh Microgreens company in Romania. Specifically, at the Tatarani farm, a system has been implemented that treats the vertical farm akin to a continuous production conveyor. This system autonomously relocates the production trays to various zones based on their specific cultivation requirements. Such a mechanism enables comprehensive yet cost-effective automation within the germination and growth areas, thereby entirely removing the necessity for manual labor.

Keywords: vertical farming, leafy greens, automation, controlled environment

S09-II-O-13

Terrestrial LiDAR enables to detect differences in canopy growth habits of mature sweet cherry trees originating from different rootstocks

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Yield, fruit mass, fruit quality attributes and vegetative growth of sweet cherry trees of two cultivars ('Bedel', 'Regina') each grafted on eight different rootstocks have been compared over a period of nine years starting from the second leaf 2014. The rootstocks can be classified according to the trunk cross sectional area into dwarfing rootstocks (Gisela 3, Gisela 5, Gisela 5 high grafted, WeiGi 2, Weiroot 720) and semi-vigorous rootstocks (PiKU1, Gisela 12, Gisela 13). 'Bedel' had the highest cumulative yields on Gisela 12, while 'Regina' had highest cumulative yields on Gisela 5, 12 and 13. In

average, the dwarfing rootstocks Gisela 3, Gisela 5, Gisela 5 high grafted and Weiroot 720 had a lower fruit mass than the semi-vigorous rootstocks, but in some years also than the also dwarfing rootstock WeiGi 2.
In 2022, 2023 the trees were scanned with a terrestrial LiDAR laser scanner from both sides after harvest. From the recorded LiDAR point clouds the leaf area per tree (LALiDAR) and the trunk diameter in 50 cm height of each tree (n=160) have been extracted. LALiDAR showed significant differences between rootstocks with trees grafted on Gisela 3 having the lowest LALiDAR and lowest leaf area per fruit ratio accordingly. In contrast, trees grafted on Gisela 13 rootstocks had the highest leaf area to fruit ratio, leading to a high average fruit mass. The LiDAR recorded trunk diameter showed positive linear correlation to the manual measured trunk diameter.
The results demonstrate, that trials to test new cultivars and roostocks in fruit trees can be supported with terrestrial LiADR laser scanners by replacing manual measurements in the often recorded trunk diameter and enabling to record the total leaf area per tree as additional canopy feature which is currently impossible to record regularly in applied trials.

Keywords: Prunus avium L., trunk diameter, TCSA, precision horticulture, yield, fruit mass, yield efficiency

S09-II-O-14

Smart monitoring of the Arnica flower development for better harvest times

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In biogenic value creation, medicinal plants are playing an important role including the commercial cultivation to meet the growing global demand. This opens up new opportunities to improve harvest quantities through breeding, cultivation management and harvesting techniques. An important aspect is the determination of optimal harvest times, which depend on the weather conditions, the state of the plant organ with regard to the harvesting process and the content of the active ingredients, which fluctuates over time. In this study, we used the medicinal plant Arnica montana “Arbo” to examine the aspect of target compound yield of helenalin, dihydrohelenalin and their esters depending on the life cycle of the flower, in order to develop methods for estimating optimal harvest time windows. A neural network was trained to classify seven stages from time-lapse images in order to track the development of each flower stage. To get typical content values, arnica plants were grown in the field and amounts of the two target compound classes were determined for each flower type. By combining both outcomes, it was possible to calculate the time course of the total amount of active compounds and thereby determine better harvest time windows. This method is interesting also for other crops where external features can be used as a proxy for active compound concentrations.

Keywords: Arnica montana; helenalin; non-invasive monitoring; flower stages; deep learning

S09-II-O-15

Novel fruit growers advisory system using connected fruit dendrometer, micro-climate data and machine learning algorithms

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The climate is having an increasing impact on agricultural production. Frequent and unpredictable events lead to physiological adaptations of plants to the detriment of fruit quality. Tomatoes, split or even burst in the summer when a succession of hot periods occur. Also apples are not well adapted to hot and dry climate; fruit size and physiological disorders affect commercial quality and storage ability. This causes important losses for the growers.
This project aims to implement and test a real-time connected fruit dendrometer in a soilless tomato culture and in an apple orchard, combined with a micro-climate analysis and machine learning algorithms. The objective is to detect a typical signature growing curve for tomato crop production and predict cracking events. As well as enable 85% of class A apple quality, by following in real-time the daily fruit growth. The research has three main outcomes: (i) improve crop quality; (ii) optimize harvest time; (iii) reduce water use.
A field trial took place in 2022 at Agroscope in Wallis, Switzerland. The behavior of 60 fruit dendrometers was tested in a soilless tomato greenhouse. Six micro-climatic stations allowed to study the dependence between climate and fruit growth. A further on-farm trial in the lake of Geneva region permitted to follow the fruit growth of 3 apple varieties managed with drip irrigation. One microclimatic station and 96 fruit dendrometers monitored the experiment.
The preliminary results revealed promising. Fruit dendrometers are reliable plant indicators for irrigation regulation in apple orchards. The build fruit-growth models can predict the final fruit diameter and the best harvest time in a soilless tomato greenhouse. Monitoring continues for generating additional data on the fruit growth behavior.

Keywords: fruit dendrometer, greenhouse, apple orchard, micro-climate, irrigation, tomato, cracking

S09-II-O-16

Radial pattern of sap flux velocity in apple trees and its consequences for the whole tree transpiration assessment

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Sap flow sensors based on the heat ratio method (HRM) provide useful information about the flow of xylem water and tree transpiration (T) dynamic but often fail to accurately estimate the actual amount of transpired water. As tree rings of different ages have different abilities to conduct the xylem sap, sap flow sensors located at different depths inside the stem provide different estimates of xylem sap velocity and therefore of T. To test this hypothesis, we measured transpiration (by load cells) of four adult vines (cv. Pinot Gris on SO4) and four adult apple trees (cv. Nicoter on M9). Plants were equipped with HRM sap flow sensors (SFM1, ICT international). To assess the radial pattern of sap velocity, the sap flow sensors were moved at increasing depths below the cambium (2, 4, 6, 8, 10, 15, 17, 19 and 21 mm) every second day in a summer period. Plants were kept under constant light and temperature conditions and well irrigated. At the end of the experiment, a dendrochronological analysis was performed to match up the depth of the sensor with the corresponding xylem ring width. In both species, the highest sap velocity was measured in the external vessels, with a peak at 2 mm below the cambium, which corresponded to 1–2-year-old rings and 4-6-year-old rings, in grapevines and apples, respectively. About 50% of the maximum sap velocity was recorded at 6-8 mm depth, corresponding to 6–7-year-old rings in grapevines and 8–13-year-old rings in apple trees. Sap flow velocity progressively decreased in the inner vessels, reaching 10% of the maximum values in 18-year-old rings in apple trees. The knowledge of radial sap velocity profile in apple trees and grapevines will allow us to fine-tune the sensor installation depth to accurately estimate the actual amount of transpired water.

Keywords: Apple, Grapevine, water uptake, xylem hydraulic conductance, dendrochronology

S09-II-O-17

Tracking the Pulse of Olive Trees: High-Frequency Data Collection Across Root, Trunk, Branch, and Fruit

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Recently, several studies about tree and fruit growth management have emphasized the significance of continuous plant-based monitoring (tracking) as a useful tool in precision farming. During the growth of a plant, various physiological changes occur within its different organs. Consequently, continuous monitoring of these organs and analyzing and comparing the collected data will play a key role in gaining insights into their dynamic trends and reciprocal relationships. In this study, continuous hourly measurements of the diameter of the root, trunk, branch, and fruit in the olive cultivar 'Rosciola' during the third phase of fruit growth (mesocarp cell expansion) were conducted using proximal plant-based sensors (dendrometer). The circadian measurement of diameters related to different organs were recorded to compare the dynamics of different organs and unveil comprehensive models. Examining the recorded trends, different correlations among different organs were found. During four weeks, a strong relationship was observed between trunk and branch (R2 = 0.79) and between fruit and root (R2=0.71), whereas the correlation between root and trunk was very weak (R2= 0.11). In contrast, when dividing experimental period into two parts, the initial two weeks and latter two weeks, a strong relationship was found between root and trunk over the latter two weeks ($R2=0.81$), likely due to a decrease in evapotranspirative demand. These results can be valuable for the development of a more precise model for smart olive management.

Keywords: continuous proximal sensing, dendrometer, precision orchard management, plant-based measurement

S09-II-O-18

Intelligent Lighting Control System for Greenhouses with a High Proportion of Local Renewable Energy

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So far there is still no complete solution where a controlled environment-plant production system is integrated to a photovoltaic system with battery energy storage for the implementation of more renewable energy alternatives. Consequently, it is rather difficult to address the optimization of the plant production and to minimize the energy consumption. In a previous work, the authors integrated a climate-controlled greenhouse with a photovoltaic system with battery energy storage to develop an intelligent control system for optimizing the operation of the lighting systems. In addition, the authors implemented a deep-learning algorithm for forecasting solar power production for the battery control purpose. A cost-benefit analysis was carried and it was found an approximate total reduction of electricity cost of about 15.3% during the experiment period. In this work, we proposed to carry out a pilot study, during the period of 22nd of December 2022 to 5th of June 2023, by setting two different light treatments of blue light proportion (2% and 14% respectively). The cherry tomato cultivar Caprese F1 was used for this pilot study. Based on the collected data, the Caprese F1 was not affected by the level of blue light proportion, as the plant height, the plant dry mass, and the total fruit yield did not show a significant difference ($p>0.05$) between the two light treatments. However, the lower blue light proportion treatment increased fruit flesh mass, fruit size, and fruit dry matter percentage.

Keywords: artificial lighting control, photovoltaic system, battery energy storage, energy consumption, *Solanum lycopersicum*

S09-II-O-19

APIC: an indoor cultivation system for optimization of high added-value productions

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The emergence of controlled environment agriculture (CEA), fueled by the development of LED lighting, is a major upheaval in plant cultivation practices. Indeed, over the centuries, nearly all efforts at growth improvement and varietal selection have been directed by the constraints of field cultivation where environmental parameters are mostly variable. CEA technologies, on the other hand, offer the possibility to adapt the environment to the plant production, rather than the other way around, therefore new production optimization strategies can be envisaged. This process implies exploring environmental variations and their effects on plant development and compositional quality, especially for high value crops such as medicinal plants. The mission of the APIC project (Automated Phenotyping for Ideotype Conception) is to provide a flexible automated cultivation platform that allows evaluation of many genotype x environment modalities in a standardized way. One important challenge in that respect is the need to provide flexible nutrient regimes dependent on e.g. genotypes, developmental stage or production targets The system presented here proposes a solution integrating a low volume hydroponic system, a gutter conveyor system, and an innovative fertigation robot that can manage many nutrient recipes simultaneously. The advantages and limitations of the platform, and its potential applications, are discussed.

Keywords: controlled environment agriculture, hydroponics, optimization, lettuce, development, medicinal plants, fertigation

SESSION III: AUTOMATION, ROBOTICS AND AI

S09-III-O-20

Semantic Explanation and Navigation for Greenhouse Robotics Systems

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Robots moving around in an open, semi-structured greenhouse environment need to avoid collisions with humans and other objects. In this paper, we focus on the challenge of dealing with unexpected but foreseeable hazardous situations for a moving robot. To deal with such situations, we developed the Semantic Explanation & Navigation System (SENS). SENS uses the recently developed standard Common Greenhouse Ontology (CGO) that represents knowledge and relations about the context of the robot's situation and possible actions. SENS uses visual object recognition to detect an object and its location, reasoning to maintain a CGO-based knowledge graph & infer more details about the situation, and an operator dashboard providing explainability. The operator interprets the explanation and gives instructions to the robot on how to continue operation. Using a tag- and beacon-based indoor positioning system, the robot is aware of the exact position of tagged objects, also outside of the field of view. We tested several unexpected situations including detection of harmless tools, dangerous tools, standing and lying humans. In each situation the robot derived the object type, the situation's severity, a message class (info, warning, alarm) and a next action proposal (bypass or turn-around). These experiments indicate that understanding of the robot's status and context increased. Next steps include more challenging scenarios with multiple

autonomous systems and improving instructions to the robot using structured natural language commands through SENS.

Keywords: semantics, explanation, navigation, greenhouse robots, human-robot interaction, knowledge modelling, reasoning, hybrid AI, artificial intelligence, computer vision, symbolic AI, robot-robot interaction

S09-III-O-21

Evaluation of Postharvest Robotic Gripping on Quality of Two Tomatoes Cultivars

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Robotic grasping poses two major challenges when dealing with fresh products: 1) the complexity of the products, characterized by irregular shapes, sizes, and deformability, making them difficult to manipulate; 2) the risk of fruit physical damage due to improper handling. Soft grippers, an innovation in materials science, offer solutions beyond traditional rigid ones. Understanding the concept of fruit physical damage is crucial in optimizing the interaction between robots and fruit. Therefore, it is imperative to establish a protocol for quantifying damage in tomatoes to ensure fruit quality preservation. This study investigated the influence of employing distinct industrial grippers to handle two tomato varieties on fruit quality, spanning quality, physiological, and biochemical approaches. Forty-five 'Roterno' tomatoes (20-82 g) and 45 'Perimo' tomatoes (90-130 g) were gripped using a three-tweezers soft gripper, while another set of 45 tomatoes from each cultivar were handled with a two-tweezers hard gripper. The gripping force was adjusted to securely hold the tomatoes without dropping them during manipulation for the soft gripper and to the minimum possible force for the hard gripper. The control group was not treated with any gripper. The quality and physiological evaluation included colour, Toloudine O Blue assay for detailed superficial inspection, firmness, weight loss, total soluble solids (TSS), acidity, pH, and respiration rate. Additionally, cell walls isolated as Alcohol Insoluble Solids (AIS) and Polyphenol Oxidase (PPO) activity assays were performed on the tomato pericarp at the contact points with the grippers. The results revealed no statistically significant differences between the tomatoes in both macro and micro analyses. This suggests that both grippers, despite their different degrees of hardness in the gripping of the fruit material, had a comparable effect on the postharvest quality of tomatoes. It is worth noting that the fruit condition at arrival limited the measurement repetitions. Nonetheless, this research contributes to the ongoing efforts in optimizing robotic handling techniques for postharvest applications, ensuring the preservation of tomato quality throughout its supply chain.

Keywords: soft gripper, hard gripper, tomatoes, postharvest handling, quality, physiology, cell wall, PPO

S09-III-O-22

New Perspectives in Modern Horticulture – "Farmbot - The Garden Robot"

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In a modern and future-oriented context, horticulture integrates advanced technologies, sustainable practices, and innovative methods to maximize crop yield and quality. The use of cutting-edge technologies by the FarmBot, such as smart irrigation systems, direct delivery of nutrients to plant roots, or early detection of specific diseases and pests, along with advanced research through the utilization of the Internet of Things (IoT) to enhance the efficiency and resilience of agricultural technologies, addresses global challenges such as food security, climate change, and sustainability. The Agricultural Robot designed and implemented in this research for activities such as automated harvesting and intelligent crop management essentially represents a friendly learning environment where programming code is used to control its movements in the field. At the same time, creating and implementing simple algorithms using function calls that require string arguments to control an agricultural robot allows for the practice of computational thinking through various examples.

Keywords: Farmbot, robot, water, management, smart

S09-III-O-23

Innovations in Agriculture: Harnessing AI and Robotics for Orchard Management Practices

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In this abstract, we delve into the forefront of agricultural innovation, specifically examining the convergence of artificial intelligence (AI) and robotics to transform orchard management. We explore various facets of this dynamic field, highlighting the transformative impact of these technologies on traditional practices and their role in ushering in a new era characterized by heightened efficiency and sustainability. The initial focus is on the pivotal role of AI in agriculture, emphasizing its application in crop detection. Advanced AI algorithms empower farmers to utilize sophisticated systems for precise detection and monitoring of crops, such as apples. This not only enhances yield prediction accuracy but also enables targeted interventions, optimizing resource utilization and minimizing environmental impact. Transitioning to robotics, we scrutinize the diverse applications of these machines in orchard management. Robots, equipped with advanced sensors and imaging technologies, autonomously navigate orchards, intricately mapping the terrain with precision. This mapping capability aids in efficient resource allocation and facilitates the development of streamlined harvesting strategies. The central theme of the abstract revolves around the integration of robotics into the harvesting process. We explore the engineering aspects enabling robots to perform intricate tasks, such as apple picking, showcasing their adaptability in dynamic agricultural environments. This transformative shift addresses labor shortages and ensures a consistently high-quality harvest. Beyond these advancements, the abstract delves into the realm of reactive learning. This approach allows robots to emulate human

behavior, particularly in harvesting. By observing and learning from human actions, robots replicate these movements and techniques, establishing a symbiotic relationship between automated processes and traditional practices. This amalgamation of technology and human expertise not only enhances efficiency but also ensures seamless integration of automation into existing agricultural workflows.

Keywords: robotics, artificial intelligence, orchard management

S09-III-O-24

Tomato robotics harvesting based on 3D pose detection algorithm using artificial intelligence

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Humanity Robotic based harvesters for tomatoes are advanced agricultural machines designed to harvest tomatoes. These robots utilize various technologies such as including computer vision, robotics, sensors, and artificial intelligence, to identify ripe tomatoes, and perform harvesting tasks.
In this paper is presented an algorithm to allow a robotic system to estimate 3d pose of tomato in order to execute the picking. Using cameras and imaging systems that capture high-resolution images of tomato plants the proposed algorithm analyze these images to identify ripe tomatoes based on color, shape, size, and texture and 3d pose, which is very important to execute the harvesting process.
The robotic harvester platform, which is an ongoing work, will be equipped with specialized end-effectors or grippers designed to pick tomatoes gently without damaging the plant or fruit. In order to control the robot we need to identify in 3D space plant, fruits, and leaves in order to estimate possible collision.
The proposed algorithm allows 3D reconstruction building high-resolution models of plants, enabling precise analysis of plant structure and fruit distribution. This level of precision of 3d pose estimation is crucial for optimizing robotic harvesting.

Keywords: detecting, images, harmful birds, crops, convolutional neural networks

S09-III-O-25

Development of a robotic solution to control slugs in lettuce crops

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Slugs are important pests in several horticultural crops such as lettuce and can cause considerable damage through feeding as well as contamination of the product. In addition to preventive measures, the application of slug pellets is currently widely used to control slug population. The aim of the study presented here is to develop an alternative robotic solution that is able to monitor the field, detect slugs and make them harmless using physical control methods. A research consortium consisting of three project partners has been established for this purpose: The Department of Agricultural and Biosystems Engineering at the University of Kassel, the company Hentschel System GmbH from Hannover and the Institute for Application Techniques in Plant Protection at the Julius Kühn-Institute in Braunschweig. Within the project, a prototype of an autonomous driving robot equipped with tracks has been built. On the vehicle is mounted a robotic arm, which is able to assume all positions around the lettuce plant. By means of a close-range 3D depth camera and deep learning model (YOLOv5s), slugs are detected on lettuce in the field under different weather and light conditions and the 3D coordinates of the centre of them are calculated. To control the slugs, various methods were taken into account and assessed. In addition to chemical and biological methods, also various physical methods can be considered. Under laboratory conditions, collecting slugs from the lettuce plant through vacuum suction has been proven to be effective against individuals with different size and weight classes and therefore, it has been chosen as control method to be further implemented. Ongoing research on the development of this robotic control solution is presented here.

Keywords: robotics, slugs, horticultural crops, lettuce, machine learning

S09-III-O-26

Vibration transmission analysis in monumental olive trees for precision pruning: the PULP System Approach

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Olive growing traditional areas are characterized by monumental olive trees. Mechanical harvesting can take place also for these trees, through the aid of branch shaking machines, but a wrong tree architecture reduces the transmission of applied vibrations. A new pruning model can improve mechanical harvesting efficiency by focusing on the study of vibration transmission in the tree. Therefore, the objective of this study is to evaluate the transmission of vibrations, to develop a model of precision pruning. The PULP system (Pruning of Unvibrating Localized Portions) records the transmission of vibrations through a series of accelerometers placed on branches of different orders. The experiment was carried out in a commercial olive grove in the Apulian region. An evaluation in pruning and harvesting was carried out followed by the record of production parameters and yield efficiency. During the pruning phase, the highest reduction of the transmission of vibration is from secondary (4.56 * 10-4 V) to tertiary branch (1.74 * 10-4 V). Similar values were observed in harvesting period, but the transmission of

vibrations inside seemed different. The detachment index showed no significant differences before and after harvesting, highlighting the fundamental role of the position of the fruits inside the canopy. The trees, on which was recorded a yield of 108 ± 7.08 kg/ tree, in the first 12 seconds of shaking led to the separation of 80 ± 3% of the total number of olives. The preliminary data obtained are necessary to better understand the vibration transmission and the different branches' behavior. Further studies are necessary in the coming years to improve and use this prototype to realize a precision pruning method for trees harvested with trunk shakers.

Keywords: CV. Coratina, mechanical harvesting, precision pruning, accelerometers, yield efficiency

S09-III-O-27

Enhancing Aloe Vera cultivation: insights from a large-scale pilot smart greenhouse with IoT and robotic device

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In recent years, global demand for medicinal plants has been increasing steadily. This study focuses on cultivating Aloe Vera within a large-scale pilot smart greenhouse installed in the University of Patras facilities. The integration of high-impact Internet of Things (IoT) technologies, installed sensors, and cablebot robotic device (KYTION) play a crucial role in measuring the cultivation process and then drawing useful conclusions. The presented greenhouse structure not only recognizes these challenges but actively tackles them through state-of-the-art measurement by IoT technologies. Preliminary quantitative results show that cultivating Aloe Vera within greenhouses demonstrates significant improvements in blooming and production, in contrast to open-crop cultivation. This presents a promising prospect for addressing the increasing demand for Aloe Vera specifically and medicinal plants in general. Also, it could utilize to the maximum degree the available arable land, labor, water, and energy, leading to stable production under unstable and variable climates. This study aims to control and automate the microclimate, optimizing conditions for Aloe Vera growth in a controlled digital environment. By contributing insights into the intersection of smart agricultural practices, technology-driven measurement and automation, and ad-hoc crop-specific cultivation strategies, this research could provide a promising pathway for the sustainable enhancement of Aloe Vera cultivation within controlled environments.

Keywords: greenhouse, aloe vera, smart greenhouse, microclimate control, IoT, robotic system

09-III-O-28

Flower detection using computer vision algorithm and three-dimensional mapping for automatic pollination using robotic platform

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Pollinators such as bees, butterflies, birds, and insects transfer pollen from one flower to another aiming the fertilization of plants. This process is essential for the reproduction of many flowering plants. Robot pollinators can supplement natural pollination by assisting in situations where natural pollinators may be insufficient or unavailable. This could be particularly valuable in areas facing pollinator declines due to factors such as habitat loss, pesticide use or indoor farming.
In indoor farming systems such as vertical farms or greenhouses, where natural pollinators may not have access or may be impractical to introduce, robot pollinators offer a viable alternative for pollination. This enables the cultivation of a wider range of crops in controlled environments, promoting agricultural diversification and year-round production.
In this paper is presented an algorithm to recognize flowers and predict 3d position of flowers. The pollinator robot will use the algorithm to execute pollination operation. A proof of concept robot pollinator is programmed to deliver precise and targeted pollination to specific plant species or individual flowers, optimizing pollination efficiency and reducing waste of resources such as pollen and energy. The algorithm uses deep learning approach in order to allow training different plants. Robot pollinators can complement but can work alongside existing pollinator populations.

Keywords: computer vision, flower detection, robotic pollination

S09-III-O-29

A realtime in-field trunk size estimation using low-cost RGBD cameras

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Trunk size estimation is important to enable crop load management on modern innovative orchards. Manual counting and sizing are labor intensive tasks that cannot be done at a scale. Robotics and autonomous vehicles can enable full monitoring of the whole field/orchard to adopt Precision Agriculture techniques at plant/tree level. In this scenario, ground vehicles or tractors equipped with RGBD cameras can be used to perform trunk cross sectional area estimation. Once the trunk is detected by a self-trained object detection Neural Network, a computer vision algorithm is the used to refine the trunk boundaries so that a pixel dimension can be reliably computed. Then, using the distance information of the object, it is possible to measure the trunk diameter so that the area can be estimated. The depth information can also be exploited as a redundant value according to the trunk size in the orthogonal axis with respect to the camera image frame. Even if this measure can be more affected by noise, it should be exploited to compare the former measurement or to detect particularly irregular trunk shapes. The camera used is an Intel RealSense D435 depth camera that features an ideal distance range of 0.5m-2m, combining color information with depth information. Experimental results are provided exploiting the Experimental fields of the University of Bologna, located in Cadriano, Bologna, Italy. The testing campaign was focused on the planar training system, as in this case, the trunk section to be measured are two horizontal

branches coming from the grafting point of the tree. The system has been mounted on the Unmanned Ground Vehicle given by the University spin-off company Fieldrobotics, featuring autonomous navigation inside orchards.

Keywords: trunk sizing, computer vision, orchard automation, orchard precision management

SPECIAL SESSION on SHEET EU-Project

S09-SS-O-31

Application of artificial intelligence in prediction of sunburn damage of fruit

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TensorFlow Lite model has been developed to get utilized in a smart farming application. Climate change induced heatwaves severely affect horticulture. Fruit damage can scale from discoloration to necrosis. While early symptoms decrease the aesthetic value, severely damaged fruit cannot be consumed or processed. Weather station common parameters were monitored and linear discriminant analysis (LDA), support vector machine (SVM) and neural network (NN) models were tested to predict sunburn damage. Models were built and validated using consecutive years for grape (2022 and 2023) while calibration of apple models was performed with one year (2023). Descriptive and cumulative parameters, as well as tendency were calculated for temperature, solar radiation and relative humidity. Ten parameters were finally selected and future damage within 72 h was estimated. The NN model with 2 hidden layers was finally selected because of the highest performance in validation and the ability to improve with new data provided by the grower as a feedback. Additionally, we could define a threshold value for high risk of sunburn damage at 15% above the average of temperature and solar radiation. The model is freely available in TFLite format for developers as well as the mobile app named SHEET for farmers.

Keywords: discriminant analysis, support vector machine, neural network, Keras, climate, weather

S06-SS-O-32

Sunburn Dynamics: Exploring Occurrence and Evolution on Vitis vinifera Berries - A Case Study of 'Sangiovese' and 'Pignoletto' Cultivars

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In recent years, sunburn and heat-related damage have increased in subtropical regions, posing a novel threat to vineyards in temperate climates. Elevated temperatures and prolonged drought have intensified berry necrosis and shriveling, resulting in reduced yields and berry quality. The SHEET project (Sunburn and HEat prediction in canopies for Evolving a warning Tech solution) aimed to address these specific objectives: i)

studying the effect of sunburn on berry composition; ii) study damage appearance and evolution in relation to berry temperature; iii) develop weather-based model to realize a warning-tech-solution for alerting growers on sunburn risk; iv) investigate the role of management practices (e.g., irrigation during ripening) in mitigating sunburn. Focusing on the points i and ii, in the first year (2021), sunburn damages were observed and characterized on both 'Sangiovese' (black) and 'Pignoletto' (white) cultivars. Additionally, the biochemical composition of healthy and damaged berries was analyzed. Sunburn necrosis appeared on the most exposed berries. Sangiovese exhibited berry shriveling about three weeks after veraison, progressing until harvest, leading to dehydration of many berries. These resulted in lower anthocyanin and flavonol content compared to healthy berries. Conversely, sunburn browning was evident only on 'Pignoletto', in particular on those berries more exposed to sunlight, and the concentration of flavonols increased with the intensification of the brown color. During 2021 and 2022 vegetative seasons, berry temperature of 'Sangiovese' vines was continuously recorded and the evolution of the sunburn damages visually estimated every week. These measurements showed that intense sunburn damages occurred when the temperature of the most exposed berries raised over 40°C. Moreover, we observed that irrigation during ripening mitigated berry temperature reducing necrosis severity. Finally, collected data have been used for developing a prototype of a warning IoT solution to inform growers on the risk of damage by means of a mobile-phone application.

Keywords: grapevine, shrivel, necrosis, heat damage, climate change

S09-SS-O-33

Orchard management changes solar radiation profiles, influencing apple sunburn

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Fruit sunburn is a physiological disorder, caused by high solar energy rates, exceeding fruit absorbing capacity. With increasing air temperatures, summer heat waves are expected to threaten fruit production in temperate areas of the globe. Apple growers are beginning to see the effects of both high radiation and air temperature, in Northern Italy, where, in summers 2022 and 2023, prolonged periods of drought and heat waves occurred. Mitigation solutions via anti-hail and shading nets are already present, however, the classic 20% shading anti-hail systems may not be enough to prevent sunburn damage on apple. On behalf of the SHEET project (Sunburn and HEat prediction in canopies for Evolving a warning Tech solution), two training systems, in Gala orchards, were compared, in summers 2022 and 2023, to evaluate the radiation interception, at different heights of the canopy and how it affected the susceptibility to fruit sunburn. A classic spindle (with and without hail protection) versus a planar cordon (with hail protection). Solar radiation interception, was measured on a clear sunny day, in the second half of July at three different heights of the canopy. Higher interceptions of ultraviolet were found in the unprotected spindle orchard, in both 2022 and 2023, whereas an effect of the training system was evident in 2023, when the planar cordon intercepted lower amounts of ultraviolet radiation. The higher the interception of ultraviolet, the higher the percentage of damaged fruit: in 2022, the uncovered spindle tested trees reached nearly 40% of damaged fruit, and nearly 20% in 2023. The protected tested trees saw damaged fruit only in 2023: nearly 3% in the spindle, while

1.3% in the planar cordon. These slight differences among protected training systems are however attributable to the irradiation interception profiles. Wall shaped trees with thin canopies (i.e. the planar cordon) are able to minimize ultraviolet radiation interception, demonstrating a further mitigation effect, along with netting protection. The training system is therefore an important aspect to be considered in orchard planning, to make future apple production more resilient to climate change.

Keywords: sun radiation, fruit surface, heat waves, light spectrum, tree canopy

S09-SS-O-34

Mobile App for analyzing the heat damage risk in grape and apple fruit

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The aim of this study was to enable farmers utilizing satellite weather data in the risk prediction of heat damage of fruit crops. To this purpose, a mobile application was developed which allows users to set up their fields with according location data, connect to a public weather API or private weather station, and then track the growth of fruit throughout the season. Based on weather data and certain growth parameters, the application uses a TensorFlow lite model trained with the available research data to predict the chance of heat damage occurring in the coming days, and recommends actions in case of an increased risk. The TensorFlow model is a Keras neural network with input normalization. The application is built on the flutter cross-platform framework, allowing software distribution to the main mobile platforms. All data is kept exclusively in an embedded database on the phone where the software was installed, and the application does not require any login or account to use, giving farmers full control over their own data. An optional and anonymized data upload is provided, via encrypted channel, so that farmer can contribute to further research and improvement of the prediction models. The data server runs in scalable cloud environment in a containerized setup and utilizes a simple database to store all data. Access to uploaded data is guarded by a state of the art IAM solution and authorization is only granted to researchers from the group of project partners, ensuring any provided data will not be available to competitors or the general public.

Keywords: handheld, software, sunburn, heatwave, smart farming

S09-SS-O-35

Chitosan-based hydrophobic bio-coatings: pre-harvest treatment improves storage quality of ‘Gala’ apple under sun exposure

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Apples are vulnerable to excessive solar radiation and high temperature, which would induce fruit damage. In order to defend apples from sunburn injury during pre-harvest stage and improve the storability through long term storage, a bio-coating with reflective TiO2 as active ingredient was developed and applied in the field by spray application. The coating recipe was adapted based on elastic modulus of coating material, resulting in the final formulation with 1 wt% chitosan and 0.25 wt% glycerol as substrate material for better adhering of coating on the apple surface. Eventually, chitosan (1 wt%)/glycerol (0.25 wt%)/rapeseed (1 wt%)/TiO2 (1 wt%) coating was applied on the apples, before T-stage and before harvest, on June 29th and August 30th. In the commercial harvest window on September 21th, fruit were harvested separately from the inner part of canopy and exposed part of canopy, capturing control and coated apples. The four treatments were stored for 2- and 5-months storage in cool and CA conditions, resulting in eight variants. Among fresh samples, enhanced L* and water content of coated apples, compared to control fruit, were found. On November 27th, coated samples showed higher L*, b*, fruit firmness, and water content, than those of control samples from in inner canopy part under CA condition. On February 13th, there were lower L* and b* and higher Fmax of coating samples than control samples from exposed growth location in the canopy under cool condition. The coating treatment improved the brightness and water content of fresh samples as well as the brightness and b* variable of samples from internal growth location as measured on November 27th, 2023. The coating treatment maintained the quality of apples during five-month storage as indicated by the fruit flesh firmness.

Keywords: apple, chitosan bio-coating, storage quality

SESSION IV: REMOTE SENSING & CVS

S09-IV-O-36

Exploiting entropy and camera distance normalization for fruit sizing by means of consumer grade depth cameras

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Fruit size and its evolution along the season are crucial parameters for precise orchard management and economical sustainability in fruit production. Fruit size and growth estimation can be performed using data related to both fruit dimensions and weight. Various approaches have been proposed to measure fruit size and growth throughout the season, such as manual sampling with measuring tape or callipers or exploiting different types of sensors able to follow the fruit size variations throughout the day or season. Despite automating the data collection, these sensors need to be managed and adapted to fruit expansion and are limited in number due to their generally high cost.
Computer vision (CV) systems (CVSs) have shown the potential to represent a solution to the issue related both to manual measures and plant-based sensors. CVSs mounted

on scanning platforms or tractors are able to monitor wide areas, increasing the sample number and reliability of the information extracted. Thanks to the recent breakthrough of CV algorithms and solutions, researchers have shown how these systems are able to detect and size fruits before, nearby, and after fruit-picking.
In this context, the presented study reports the performance of a CVS based on consumer depth (RGB-D) cameras and neural networks to detect and size fruit in the field. Fruit detection is based on an innovative approach that employs image lightness entropy analysis to precisely identify the fruit perimeter, together with a virtual movement of the target object closer to the camera, to improve fruit sizing performances. Results on different timings along the season show a mean error of -4.6mm, an RMSE of 6.3 mm, and a correlation of r = 0.95 in estimating fruit size, higlightin improved performances compared to previous experiments based only on color analysis applied on the same data.

Keywords: fruit sizing, depth cameras, neural networks, entropy, distance normalization

S09-IV-O-37

Diagnosis of ˈCa. Phytoplasma maliˈ infection, and nutrient deficiencies in Malus domestica trees via in-vivo spectroscopy

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Apple proliferation, associated with infection by 'Ca. Phytoplasma mali', is an economically important disease of apple, particularly in Europe. Because there is no curative treatment, the management of the disease lies primarily within management of the insect vectors of 'Ca. P. mali' and the eradication of infected trees, which must be diagnosed by costly and time-consuming molecular analyses or according to the presentation of symptoms that often requires expert knowledge. To complicate matters further, infected trees do not always present symptoms, and other stresses, especially mineral nutrient deficiencies such as those in N and P, cause similar symptoms. Preliminary work has shown that on-site spectroscopy has the potential to overcome these obstacles for the diagnosis of 'Ca. P. mali' infection and serves as the basis for other methods that could potentially be applied easily and economically within practical settings. In this presentation, further results elaborating on the diagnosis of 'Ca. P. mali' infection based on an in-field spectroscopic method, as well as results of a potted trial relating to the performance of the same method for diagnosis when other trees are experiencing moderate and severe N and P deficiencies, are presented and compared. As previously observed, predictive ability using data collected in-field, from late spring through summer, was negligible but increased drastically as the growing season progressed. Results from April were inconclusive. Multiclass PLS-DA models from the potted trial were highly successful and also increased as the growing season progressed. These models were more complex than the binary “in-field” models and required wavelengths distributed widely across the spectrum.

Keywords: Apple proliferation, proximal remote sensing, vegetation index, machine learning, support vector machine, Partial Least Squares-Discriminant Analysis

S09-IV-O-38

Use of satellite images to estimate olive production

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Accurate and timely estimation of olive productivity is crucial in the olive growing industry, representing a tool for improving profitability and ensuring sustainable farming practices. This study aimed to assess the feasibility of several vegetation indices (VIs) in estimating olive fruit production. It was conducted on three commercial olive orchards, with different cultivars ("Verdeal Transmontana", "Madural" and "Cobrançosa"), located in the Northeast of Portugal. Different irrigation strategies were imposed, including full irrigation, sustained deficit irrigation and regulated deficit irrigation. Using multispectral data with a 10-meter resolution obtained from Sentinel-2 throughout 2019 (from May to December), VIs were computed to examine trends among them, showing a gradual decline in values up to the harvest date. Furthermore, the one-year results revealed distinguished discrepancies in production estimates derived from VIs across different cultivars "Cobrançosa" showed the best relationship between VIs and olive fruit yield, with a strong positive linear relationship ($R2 > 0.8$) from early August to mid-October, with peak correlation observed in the third week of August ($R2 = 0.93$) when using the Normalized Difference Vegetation Index (NDVI). Through the combination of data from all the three cultivars, several indices were able to perform effectively in yield estimation from May to November. Although these findings are preliminary, they suggest a promising use of VIs for early estimation of olive orchard production.

Keywords: *Olea europaea* L, precision agriculture, Sentinel-2, vegetation indices, production estimation

S09-IV-O-39

Remote sensing in precision fruit farming: Estimation of spectral response in olives irrigated with saline reclaimed water

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Remote sensing in fruit farming is an innovative technology for sustainable fruit production. This study evaluated the effectiveness of unmanned aerial vehicles (UAVs) equipped with multispectral cameras for identifying water and salt stress. The experiment was conducted in potted olive trees (Olea europaea ‘Arbosana’) planted under Mediterranean conditions and subjected to two irrigation strategies (Full Irrigation and Regulated Deficit Irrigation) combined with two water resources: low-cost water DEsalination and SEnsoR Technology (DESERT, ECw ~1 dS m−1) and reclaimed water (RW, ECw ~3 dS m−1). Flights and leaf measurements were conducted twice a day (early morning and midday) throughout the irrigation season. The dataset included UAV’s single bands, different Vegetation Indices (VIs) and physiological parameters, i.e., stem water potential (Ψs), and leaf water potential (Ψl). After image processing and data analysis, the results showed that remote sensing method can identify water stress within the different treatments, which consequently can lead to several benefits, such as safe and sustainable wastewater reuse in agriculture. Positive results have been obtained with VIs, including near-infrared (NIR) and red-edge bands. Different VIs were significantly correlated with water status, and the highest Pearson correlation coefficients were obtained with Normalized Difference Red-Edge (r=0.85 for Ψs and r=0.81 for Ψl) and Normalized Ratio Vegetation Index (r=0.85 for Ψs and r=0.81 for Ψl) for the olive trees under regulated deficit irrigation. However, the r values obtained were lower for olive trees under full irrigation; the best results were achieved with the NIR band for Ψs (r=0.45) and the Optimized Soil Adjusted Vegetation Index for Ψl (r=0.58). These results demonstrated that applying multispectral bands and VIs can provide a faster, cheaper, and simpler alternative to traditional field measurement methods.

Keywords: deficit irrigation, *Arbosana*, precision agriculture, olive, water management

S09-IV-O-40

Remote sensing of the plant responses to biostimulants with electrophysiology

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Novel methods of acquiring and analysing electrophysiological signals enabled remote recording and fast evaluation of several agronomically important aspects of plant states e.g. responses to environment, drought stress and nutrient deficits. Distantly recorded electrophysiological responses of pepper and mandarin plants grown in commercial conditions and treated with Croptimum were evaluated. Treatment resulted in yield increases and induced similar electrophysiological responses in both plant species. The biostimulant increases periods of optimal plant growth and enhances plants' responses to light as well as decreasing stresses related to water deficit, high temperatures and humidity variations. Most of electrophysiological metrics indicate positive effects of biostimulant treatment from the time of the first application for mandarins and after the 4th application for pepper plants. Remote sensing of the electrophysiological signals enables real time diagnostic of the plant state and delivery of actionable insight to the growers in the scale of minutes from the time of event detection.

Keywords: biostimulants, mandarins, peppers, plant electrophysiology, drought stress

S09-IV-O-41

Peach tree canopy assessment through aerial image detection for improved management and sustainability

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Precision agriculture aims to detect differences in plant development within a defined area, allowing to adjust production techniques according to the plant development. Plant development is evaluated by remote detection allowing the application of Variable Rate Application techniques. The efficiency of precision agriculture is correlated with large areas of the same crop where is plants development are highly correlated with soil characteristics variation. The application of precision agriculture in fruit production is common in the species that allow mechanical harvesting, and, consequently, allows obtaining yield maps. Peach production is carried out by manual harvesting and is usually based on medium-sized parcels, as the fruit is very perishable and harvest window for each cultivar is short, from 10 to 15 days. This paper describes the experimental tests developed to evaluate the volume of peach tree canopy, based on images captured by a drone, and its correlation with trunk section area, which is a common way of assessing tree vigor. Ten plants per orchard were monitored in 20 different orchards. The correlation between tree canopy and nutritional status was developed using the orchard as the repeating unit.

The results indicate that projected canopy area, evaluated by aerial images, is directly correlated with tree canopy volume, in full developed orchards, as tree height is standardized in every orchard according to the training system. The remote assessment of the tree canopy allows the adoption of differentiated techniques that contribute to better management focused on a greater income to the farmer and, at the same time, contribute to environmental sustainability.

Keywords: *Prunus persica,* tree canopy area, trunk sectional area, nutritional status, aerial imaging, image detection and classification

POSTER PRESENTATIONS SESSION I

S09-P-I-42

First results of a digital outdoor laboratory through integration of various systems for measuring soil moisture and plant water status in fruit growing

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A shortage of specialised workforce, climate change, increasing regulations to protect the environment and the consumption of resources pose major challenges for fruit growing and viticulture. Digital technologies such as sensors, robots and satellite systems are therefore becoming more and more common in these sectors of agriculture. To test and validate such technologies under field conditions, in 2022 two digital outdoor laboratories named LIDO - Laimburg Integrated Digital Orchard - were created at the Laimburg Research Centre, Vadena, Italy, one in a vineyard and the other in an apple orchard. In the first case, an existing vineyard of the variety Chardonnay was chosen, while in the case of apple an orchard was newly planted with the variety Rosy Glow Pink Lady® and a Guyot training system. Both fields are connected to electricity and fibre-optic communication. A remote-controlled, fixed spraying system for the application of plant protection products was integrated. The outdoor laboratories are now available for companies, research institutions and interested parties to test their products and demonstrate them to the public. In spring 2023, 14 different systems for measuring soil moisture and plant water status from regional, national and international companies were integrated into the outdoor laboratory in the apple orchard. The collected data and experiences are analyzed in order to characterize and recommend the different tools to growers, researchers and technicians.

Keywords: digital orchard, digital vineyard, smart farming, digital outdoor laboratory, sensors, soil moisture, plant water status, fixed spraying system

S09-P-I-43

Alternate production technologies for sustainable production of horticultural crops

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Growing population and climate change, coupled with diminishing land and water resources, can pose a threat to horticultural crop production through the use of conventional methods. The exploitation of alternative production technologies can contribute to real solutions for these challenges. The adverse effects of using inorganic inputs and the low efficiency of inputs insist on adopting alternate technologies. To ensure optimum production of horticultural crops, it is essential to consider environment-independent cultivation, precise resource application, vertical space utilization, soilless

cultivation, the introduction of new crops and tolerant varieties, organic resource utilization, the use of new and renewable energy sources, artificial light usage for increasing production efficiency, minimum or zero-budget farming, automation in plant monitoring, exploitation of horticulture in urban and peri-urban areas, and the use of drones and sensors for disease identification and management. The technological gap between scientists and farmers needs to be reduced and there is a need to increase the number of studies to standardize these technologies in different horticultural crops.

Keywords: alternative approaches, input use efficiency and productivity

S09-P-I-44

Predicting foliar N and P concentrations in apple using UV-VIS-NIR spectroscopy - moving beyond the proof of concept

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Optimal nutrient management is critical for the sustainable and environmentally friendly management of crop systems. Leaf reflectance spectroscopy is a practical and cost-effective method for the determination of foliar nutrient concentrations that can be performed in the field and serves as the basis for other methods for foliar nutrient estimation that are highly scalable. Using UV-VIS-NIR hyperspectral reflectance profiles of leaves from potted apple cv 'Golden Delicious' trees with a spectroradiometer, we predicted leaf N and P concentrations accurately and efficiently using partial least squares regression (PLSR). This was despite a wide range of foliar N and P concentrations and despite some trees also being infected with 'Ca. Phytoplasma mali ' providing evidence for the robustness of the method in the face of perturbing factors. We also found that the wavelengths important for the estimation of N and P were distributed widely across the full range of the instrument (350 nm to 2500 nm). Selecting important wavelengths using the mRMR algorithm, which minimises redundancy between the selected wavelengths, as opposed to VIP, produced better results when few variables were selected. Predictions of P were better when they were made based on spectral vegetation indices (SVIs) rather than full spectra. The use of SVIs also performed better than the use of full spectra for the estimation of N when the number of variables used in the model were few. This has implications for the practical application of reflectance-based technology in the field.

Keywords: remote sensing, plant nutrition, chemometrics, automation, precision agriculture, sustainable agriculture, spectroradiometer

S09-P-I-45

Intelligent pest control: AI-driven solutions for sustainable agroecosystems through remote surveillance and descriptive modeling

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Recent climatic changes are challenging to phytosanitary management, especially in pest control. Fluctuating temperatures and irregular precipitation disrupt the life cycles of acclimated species like the Mediterranean fruit fly (medfly) Ceratitis capitata, causing increased damage to fruit crops. Conventional large-scale capture and pesticide strategies are proving ineffective in the face of evolving eco-sustainable agricultural practices. Human activities, especially trade, have introduced exotic species such as the oriental fruit fly, Bactrocera dorsalis, to Southern Italy, exacerbating the complexity of the issue. To address these challenges, there is a growing reliance on Artificial Intelligence (AI) for innovative pest management. The Up-TrAPS project focuses on an in-depth study of C. capitata, aiming to update its life cycle information and assess its response to the invasion of B. dorsalis. A comprehensive monitoring network, incorporating traditional and electronic traps, utilizes Deep Learning techniques for enhanced species recognition. Six infested fields are continuously monitored, employing not only traps but also smart control units for frequent agrometeorological and soil trend measurements. To clear up pest phenology and population dynamics, the combination of agrometeorological and entomological data, mathematical models based on the matrix, and Ordinary Differential Equation (ODE) functions are employed. Various Machine Learning approaches, including Artificial Neural Networks, are tested using agrometeorological data and pest presence/absence to develop a predictive model for both species. Preliminary degree days analysis reveals a shift in the life cycle of C. capitata and a delayed appearance of B. dorsalis in 2023. These findings underscore the necessity of updating Ceratitis capitata life cycle data and propose hypotheses for potential new invasions of Bactrocera dorsalis. The integrated approach, utilizing AI and updated descriptive models on phenological data, emerges as a crucial tool to be incorporated into Decision Support Systems for effective and sustainable phytosanitary management.

Keywords: phytosanitary management, climate change, pest control, artificial intelligence in pest management, invasive species

POSTER PRESENTATIONS SESSION II

S09-P-II-46

A review of current technologies for detecting and deterring harmful birds in horticultural crops

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Humanity needs food to survive, and most food comes from crops. Agricultural crops around the world are often destroyed by various pests, including birds. They attack different crops, usually in large flocks, often similar to other groups causing major damage to farmers. They tried different methods of repelling birds from cultures (scarecrows, balloons, kites, models with raptor birds, reflective tapes, devices that emit sounds and ultrasound, lasers, etc, even drones equipped with various auditory or visual systems, and other), but none of these offer them complete crop protection. Recent research in the field, based on artificial intelligence, show new models of crop protection systems using machine learning algorithms, which helps to recognize birds based on neural networks. Bird detection and localization is a superior application of computer vision. After the target bird has been identified, the emission of specific sounds and or ultrasound occurs, different for each species, the system then automatically selects the appropriate bird-rejection sound and plays it to specifically scare the birds away. Learning-based methods are advanced methods because they help detect and locate birds through images, approach the conditions in which the birds presented are various in shape and size and most importantly show the complex environments in which they survive. In this regard, this paper presents a review of the current systems existing in the world, for the detection of harmful birds in crops, developed and recently presented by researchers in specialized papers.

Keywords: detecting, images, harmful birds, crops, convolutional neural networks

S09-P-II-47

Automation and robots in vertical farming

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In addition to the expanding population and corresponding increase in food demand, conventional farming faces a number of challenges. First and foremost, the yield is highly dependent on the weather and other external, uncontrollable variables. Unexpected droughts, excessive precipitations, pests, etc., can harm crops beyond repair, causing farmers' losses and upsetting food supply systems. Crops can be shielded from inclement weather and hostile settings by practicing indoor vertical farming. In addition to providing shelter from the harmful elements, the seclusion keeps weeds, insects, and other undesirable plant deterrents at bay. In order to enable optimal crop growth free from agronomic constraints, vertical farming is an energy-intensive crop production system that integrates a number of technologies, including robots, artificial intelligence, big data analytics, and the internet of things. In order to facilitate various hardware integration, data collecting, data analysis, and automated control of the installed devices within the structures, vertical farming structures depend on comprehensive solutions. In the future, newly constructed vertical urban farms will not only lower production costs and enhance harvest yields, but they will also greatly improve the quality of agricultural products supplied to urban population, minimizing the negative environmental effects of urbanization. This paper describes the main characteristics of vertical farming systems, as well as automation components and robots used in these systems, also giving insight on constraints in establishing a vertical farm.

Keywords: climate changes, controlled environment, increased crop yield, automated growth systems, agricultural robots

S09-P-II-48

Explainable Machine Learning to Advance Eco-Physiological Prediction

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Stomatal conductance (gs) is a key leaf-level function controlling water and carbon exchange between vegetation and surrounding environment. Semi-empirical models of gs are widely utilized in terrestrial biophysical simulation to resolve energy balance and biochemical processes related to the land-atmosphere exchange of carbon, water, and energy. These semi-empirical models for gs are typically based on regression relationships with environmental conditions and require re-parameterization as the plant growth evolves throughout the growing season. Machine learning (ML) models offer a potential path to overcome this problem through the development of flexible, data-driven models. Here, we discuss an evaluation of ML as an approach to develop flexible and robust models of gs for a range of plant functional types. Particular focus is placed on models formulated around predictor sets that are: (a) relevant to gs estimation in modern terrestrial biophysical simulation models, and (b) composed of variables describing environmental and physiological drivers that can be remotely sensed non-invasively. The outcomes of the ML models were interpreted through an explainable ML approach. The results demonstrated that ML models significantly outperform conventional semi-empirical models in predicting gs responses. We also demonstrate the power of explainable ML in providing valuable insights by unravelling instance-based and global explanations of modeling outcomes, while illustrating that the models are consistent with the underlying ecophysiology. This work demonstrates the use of ML as an integrative tool to complement process-based modeling in land-surface models.

Keywords: stomatal conductance, plant ecophysiology, explainable machine learning

S09-P-II-49

Stretching the limits: monitoring apple fruit growth with an ultra-stretchable strain sensor

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Fruit growth is a complex process influenced by various biochemical and biophysical mechanisms, environmental factors, as well as management practices. The growth of various fruit species has been studied extensively, especially in terms of fruit diameter, as this is as a key parameter for analysis. Of particular importance in precision orchard management is the possibility to continuously measure fruit growth. At this aim, it is necessary to develop instruments that can withstand harsh orchard environments and accurately report fruit expansion without interfering with fruit physiology. Various methods, including transducer sensors, strain gauges, and linear potentiometers, have been proposed for continuous fruit growth monitoring. However, fruit growers have been slow to adopt these instruments, possibly due to the lack of user-friendliness, the high costs associated with the use of these techniques in measuring campaigns, as well as the maintenance required. Here, taking advantage of the progress that the field of flexible and stretchable electronics has recently experienced, we propose a novel, minimally invasive, and stretchable resistive strain sensor as an alternative to address this challenge. The proposed sensor, capable of operating in a laboratory environment at up to 100% strain, utilizes variations in its electrical resistance upon mechanical deformation. The initial design will feature a serpentine layout made of stretchable conductive ink, along with silicone rubber encapsulation. The silicone rubber will encase the serpentine layout within a sandwich structure created through successive layer coating. To identify the optimal combination that meets all requirements and constraints, a thorough material investigation will be conducted. This innovative strain sensor offers potential for adoption in continuous monitoring of fruit growth. It is affordable and requires little to no maintenance once installed. This paves the way towards real-time data acquisition on fruit growth, enabling timely advice for decisions on irrigation management, fruit thinning, and harvest predictions.

Keywords: strain sensor, dendrometer, fruit growth, fruit sizing, plant wearable, continuous monitoring

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Robotic harvesting methods for vegetables from the Solanaceae family in greenhouses and solariums using specialized grippers - review

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In the development of agriculture of the future, robots have an important role and offer many advantages in agricultural production. Harvesting represents one of the most complex processes in agriculture which could benefit from robotic applications, due to the precision and swiftness that robots can obtain to improve crop yield and minimize losses. Methods for robotic harvesting of vegetables from the Solanaceae family use robotic arms or similar devices equipped with specialized grippers, operating on different fruit detachment principles. These are essential components of robotic manipulators, serving as the robots' devices to perform picking and placing activities. Vegetables' grasping not only requires direct contact but also blocking potential slips and damages while vegetables are being harvested and stored. The article presents a series of robots from the current state of the art, operating on different principles adapted to the specific characteristics of the targeted Solanaceae species and the advantages of their use.

Keywords: specialized grippers, automatic picking, protected spaces