A multispectral acquisition system for potential detection of Flavescence dorée

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***Abstract*—Agriculture is under constant pressure to increase the production rate and to provide more food or resources for other industries. Without precision agriculture it is not possible to fulfil these requirements. Medium and large-size farms already adopted this technology, but small farms are far from precision agriculture due to the high initial costs. In this paper we present a bespoke and affordable multispectral camera for precision farming and illustrate its application in the detection of Flavescence dorée. This is a grapevine disease that makes a great concern to grapevine producers in the whole Mediterranean region. Flavescence dorée is the only quarantine disease in the European region. The related mandatory control procedures include uprooting every infected plant, with the obligation to uproot the vineyard when the infection exceed the 20% of threshold infection, hence resulting in a high economical loss. Thus, it is highly important to detect even a single infected plant over an entire vineyard plot, preventing the spreading of Flavescence dorée at earliest stages. We used the in-house developed multispectral camera together with a hyperspectral camera to acquire data from two vineyards near Riva del Garda, Trentino, Italy, during the summer of 2022. These data are the starting point for selecting the optimal spectral bands for the detection of Flavescence dorée using affordable multispectral approaches and developing an appropriate classification algorithm.**

Keywords—Precision agriculture, Multispectral camera, Hyperspectral imaging, Grapevine disease detection, Flavescence dorée.

I. INTRODUCTION

Agriculture, as a provider of the most basic needs of the population (food and fiber), is under constant pressure to increase the production rate [1]. More than tripling world population from the 1950s to 2022 [2], climate changes and expansion of only 30 % of the cultivated areas [3] are the main reasons for the demand to improve agriculture efficiency. Given the limited amount of available arable land, a significant part of this constantly growing request can be fulfilled through agricultural intensification: higher usage of fertilizers, pesticides, water, and other inputs. However, this can cause ecological issues, especially environmental pollution, most prominent through the contamination of drinking water and aquatic ecosystems [4],[5]. Also, unoptimized fertilization, irrigation, and pesticide usage reduce agriculture's economic gain.

Precision agriculture (PA), a key component of sustainable agriculture in the 21st century [6], is trying to address those issues. There are several definitions of PA, but the underlying principles are the same [7]: it is a site-specific crop management concept based on observing, measuring, and responding to the variability in crops. The aim of PA is to design a decision support system (DSS) to manage the farm with the main goal to maximise returns while preserving the environment.

The most common way to obtain information about the state of vegetation is by multispectral (MS) imaging. MS can provide information about the vegetation indices, among which the Normalized Difference Vegetation Index (NDVI) is the major indicator of the crop conditions and the health of the plants [4]. The usual way for obtaining MS images is from airplanes or through satellite. This has several limitations: although free multispectral satellite images are available every few days (e.g. with Sentinel 2 constellation), a common clouded condition in Europe regions complicates image usage [8]. In addition, the image resolution (10 m per pixel) can be insufficient for problems detection within crops due to it measures average reflectance in the areas corresponding to each pixel [9], while free software solutions are complicated for non-expert use.

A possible flexible and effective solution it to use MS cameras mounted on the UAV (Unmanned Aerial Vehicle - Drone). PA is not only reporting status of main crops but also enables site-specific application based on a user-friendly DSS. This approach is indeed already adopted by medium and big farms. Unfortunately, small farms are still lagging behind in the application of PA, due to large initial costs [10], especially within the highly fragmented arable land in mountain zones [11], like Greece and Italy [12]. Yet, in the EU small farms make up to 67% of all farms in the EU [13], and for their sustainability it is crucial to adopt PA. Additionally, the importance of small farms in Europe is beyond commercialization, they contribute to social capital, local knowledge, and cultural heritage [13].

The most common applications of PA are yield prediction, irrigation and nutrient management, disease and weed monitoring and management [14]. Selecting a

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Findings presented in this paper are results from “MCAPEFA” projects. This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 101028085.

particular challenge that PA tries to address is region-dependent. For example, in Trentino (Italy), the most abundant cultivated plants are apples and grapevines. In recent years, producers of grapevine, especially in Italy and France, very frequently had problems with Flavesence dorée (FD) [15], which is grapevine phytoplasma–borne disease transmitted by the leafhopper Scaphoideus titanus Ball [16]. FD is considered one of the most important diseases for the European principal wine-production areas. FD is the only quarantine disease in the European region, and the mandatory control procedures include uprooting every infected plant [17]. It is therefore important to detect even a single infected plant over an entire vineyard plot [18], preventing the spreading of FD not only in the monitored vineyards but as well as in the neighbouring ones, hence reducing economic loss. FD's main visible symptoms appear in the summer and can be spotted until mid-autumn. The symptoms are expressed as dying of the inflorescence and berries, leaves curling downwards, and becoming yellowish or reddish in white and red cultivars, respectively [17],[18].

In order to address both stated issues, i.e. adoption of PA on small farm's level and the automatic detection of FD, in this paper we present initial studies on developing an affordable multispectral camera and acquiring field data for further investigation on possible detection of FD using MS images.

The prices of commercially available MS cameras depend on the number of different spectral band. They range from several hundred euros for RGB + NIR, like Mapir Survey3, tu much higher costs for cameras that include more narrow spectral bands like Sentera 4K (five bands), Sentera 6X (six narrow bands), and MAIA S9 (9 narrow bands). When a thermal camera is included in the same housing (AltumPT), price can reach 20 Keuros. Other realisations found in the literature are based on special sensors or optics. Ono [19] presents MS camera realized using an industrial camera with four directional polarization filters on each quad pixel and special design lens with 9 bandpass filters. P.J. Lapray et al. [20] described a solution based on a standard CMOS camera and a specially designed 9 bands multispectral filter array placed on the top of the sensor. Both these approaches have shown good performance but are based on components that are not directly available on the market. A different idea was independently demonstrated in [21] and [22], where the authors proposed to use colour cameras, triple/quadruple bandpass filters either with a beam splitter and two colour cameras or a rotating wheel, obtaining 8 or 18 spectral bands, respectively. The problem with these two designs is a bulky system or the possibility of imaging only slowly moving objects, which is inappropriate for mounting on UAV.

In the next section, we describe designed multispectral camera and an intention to use it for detection of FD, following with the method to acquire hyperspectral and multispectral images, while in section IV we explain the initial findings. Finally, the conclusion and suggestions for future work are presented in Section V.

II. MULTISPECTRAL ACQUISITION SYSTEM FOR POTENTIAL DETECTION OF FLAVESCENCE DORÉE

Based on these approaches [21],[22], we designed a multispectral camera which consists of commercially available components: Raspberry Pi 4, Arducam Quad-Camera Bundle Kit and 4 single/dual/triple bandpass optical filters. In this way, we get spectral responses in 9 bands, and this system doesn't contain moving mechanical parts or precisely-aligned optical components. Additionally, we added a thermal camera, Seek Mosaic Core, with a resolution of 320x240 pixels, since there is a detectable thermal difference between healthy and infected plants [23]. The selected components are easily available and their total price is also far below standard multispectral cameras with a similar number of bands, which drastically reduces the initial cost for the adoption of PA at small farm level.

As grapevine is one of the highly cultivated plants in the Italy, we decided to investigate the possibility of detecting Flavescence dorée (FD) in commercial vineyards. There are several attempts to detect FD in remote sensing literature, using hyperspectral or multispectral cameras. A large body of evidence shows that FD alters photosynthetic capacity along with other morphological effects (e.g. leaf rolling).

In [17],[18], the authors used standard multispectral cameras (5 bands) and concluded that although it is possible to detect FD, the success rate depends on the variety (red or white grapes) and there are no same vegetation indices for all examined vineyards and varieties that have shown high correct classification rate. Also, misclassifications could be related to the presence of mixed soil/vine vegetation or shadow/vine vegetation pixels. This can be improved with better vine vegetation masking. Bendel et al [24] tested the possibility of detection of the FD using hyperspectral data, with a high correct classification rate, but in laboratory conditions, with constant light, where leaves are positioned on the uniform surface and separation from the background is straightforward. Thus, additional work must be conducted to select optimal bands for application in vineyards. In [25] authors acquired hyperspectral images in laboratory conditions and validated the possibility of FD detection using a hyperspectral camera and a deep learning approach, showing that this approach needs further work to adapt for in-field testing and to reduce the dimension of the input image by reducing the number of spectral bands. AL-Saddik et al. [26] conducted studies obtaining hyperspectral data in the field with a handheld device, taking 4 samples per inspected leaf. They concluded that there was no single best index for detecting FD in all situations. The best index depends on the grapevine variety, soil, vegetation, and weather conditions, but the development of indices based on spectral variations due to FD is feasible and should be adapted to the specific situation. Similar findings were presented in **Error! Reference source not found.**, showing that a right selection of spectral bands enables FD detection.

In our research, we decided to use a similar approach but to simultaneously acquire hyperspectral and multispectral data in 9 bands. We selected the two most common varieties in the Trentino region, one white, Chardonnay, and one red, Cabernet Sauvignon. The hypothesis behind the study is that the differences in spectral signature introduced by the presence of FD differ between two varieties. The hyperspectral data are redundant and after we will find the smallest number of spectral bands needed for classification among healthy and infected plants, we will project this reduced spectral signature to the bands of developed multispectral camera. This can provide a light and inexpensive platform for FD detection, reachable by the owners of small farms. Additionally, the same principle can be applied to others plants species, finding the best spectral bands to differentiate between healthy and infected plants using hyperspectral imaging and then optimizing bands of the multispectral camera to obtain an inexpensive and low footprint device.

III. DATA ACQUISITION

As it was stated, a multispectral camera is designed using four RGB global shutter sensors (OmniVision OV9782), which are available as a development kit for Raspberry Pi 4. To obtain 9 different spectral bands, 4 different passband filters are mounted on lenses. Central wavelengths of filters are: filter 1 (432 nm, 517 nm, and 615 nm), filter 2 (577 nm and 690 nm), filter 3 (750 nm), and (filter 4: 550 nm, 660 nm, and 850 nm). To get a direct response in the all passbands, we conducted a reconstruction process based on linear regression as is described in [21],[22].

As a target, the X-Rite® ColorChecker Classic was used, with A4 size containing 24 patches of different uniform colors. Ground truth spectral responses for calibration multispectral cameras were acquired using hyperspectral scanner HySpex Mjolnir V-1240, with 200 channels in the 400 – 1000 nm range, and 1240 samples in each channel. Light was supplied by QTH (Quartz Tungsten Halogen) as a broadband source of illumination without discontinuities in the spectral range of interest.

Campaigns for obtaining hyperspectral and multispectral images were conducted on 12th July, 23rd August, and 22nd September 2022, in the two vineyards around Riva del Garda.

The acquisition setup is presented in Fig. 1. The hyperspectral scanner was mounted on a slider to provide the moving necessary to obtain the hyperspectral image. The multispectral camera was mounted on a standard photographic tripod. As the proposed imaging device has an infrared camera, we added a high-quality thermal camera, FLIR Duo Pro R, as a reference thermal sensor. Thermal data will be examined in the future to investigate new possible contribution to improve the detection of FD using multispectral images.

Fig. 1. Devices used for image acquisition.

Assessment of plant status (healthy or infected) was performed in the field, by a local expert who, on regular basis, visually observes vineyards to spot newly infected plants. Examples of symptoms in red and white varieties are displayed in Fig. 2.

IV. INITIAL RESULTS

Calibration results for the multispectral camera are shown in Fig. 3 The left image presents a reconstructed calibration board, while the right displays how well multispectral samples fit the profile for one patch and for one spectral band. The R^2 coefficient, as a measure of how well the regression predictions approximate the real data, is higher than 0.96 for all 24 patches and for all 9 spectral bands, indicating that the designed multispectral system operates as expected.

Fig. 2. FD symptoms in red (left) and white (right) grapevine variety.

Because field campaigns were just finished at the of the preparation of this paper, we present the results on only few images.

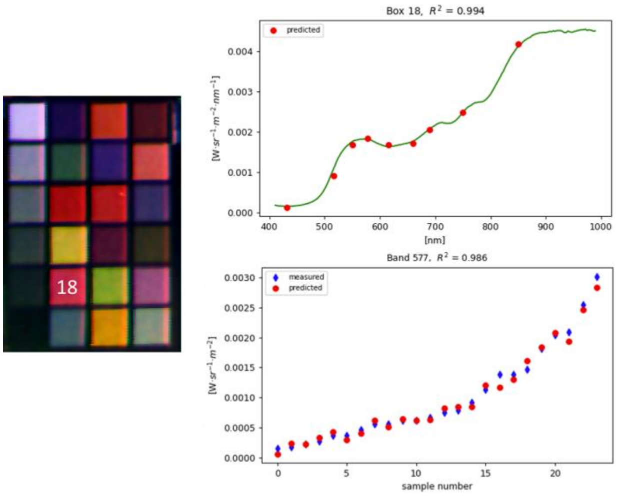

Fig. 3. The reconstructed image of the calibration target (left). Reconstructed radiance at the central wavelength of each band for patch 18 (top right). Measured and reconstructed radiance at 577 nm for each patch sorted in ascending order of radiance (bottom right).

Hyperspectral data shows some differences in spectral signatures from leaves of plants that express symptoms of Flavescence dorée, as is shown in Fig. 4. The main differences are in the blue and red bands, and these findings are the starting point for selecting bands that mostly differentiate between healthy and infected plants and designing an appropriate algorithm for the classification.

V. CONCLUSION

In this paper we have presented a multispectral camera based on commercially available components which can provide 9 spectral bands. Proposed camera has a price several times smaller than similar commercial solutions lowering the initial investment for adopting precision agriculture tools, especially at small farms level. Small farms present about 2/3 of all farming land in the EU, but without the use of PA their sustainability may be questionable. However for Europe, it is vital that smart farms continue to exist, due to their social capital, local knowledge, and cultural heritage.

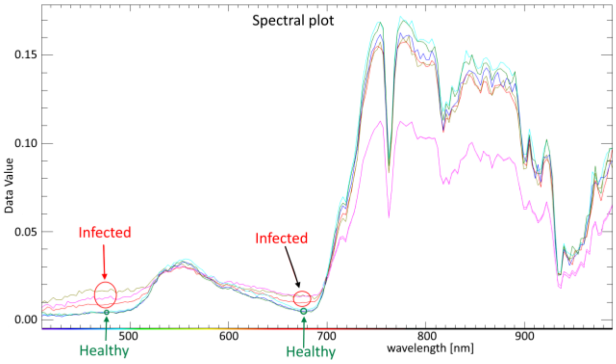

Fig. 4. Several spectral profiles for healthy and infected leaves.

We have presented a test case with hyperspectral, multispectral, and thermal data, that will be the starting point for investigating the possibility to detect FD, which is the grapevine disease of the greatest concern for many grapevine producers across Europe. We acquired hyperspectral and multispectral data at the same location in the field, and under the same natural lightning conditions, which fits real word scenarios. On the basis of these data we will design a pipeline to select the smallest number of spectral bands that can detect FD in different grapevine varieties.

Besides stated activities for future work we will adapt this approach to the acquisition using UAV, which drastically reduces the time needed to collect data for the whole vineyard. The implementation of the pipeline will limit time-consuming and expensive visual assessments of the plant status that, at the moment, is carried out by trained agronomists and experts.

ACKNOWLEDGMENT

The data collection for this research was done at two vineyards managed by the Agraria Riva del Garda. We thank Agraria Riva del Garda company with its associates and Michele Mutinelli from Agraria for making it possible for the collection of the data and for providing domain expertize.

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