Field robot to detect plants infected by *Candidatus Liberibacter* solanacearum in horticultural crops using multispectral computer vision

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Abstract

A low cost field robot has been built capable of transporting a series of sensors through horticultural fields, with the aim of early detecting problems in the crop by means of proximal sensing techniques. The robot is operated by remote control and is driven by two electric motors coupled to the wheels and powered by batteries. The sensors include different thermal, colour and multispectral cameras in the visible and the near-infrared range that are synchronised with the advance of the robot by means of an encoder coupled to the axis of the motors. The position of each image is geolocated using a GPS. An industrial computer receives the encoder pulses and triggers the cameras, also receiving and storing the images and GPS information for further processing. The inspection area is located beneath the robot with the cameras focusing downwards (to the crop). To avoid the negative influence of direct sunlight, the area had been covered with a canvas and illuminated artificially with four-spot halogen lights. A telescopic extension system between 100 and 200 cm allows the robot to adapt to crops with different row widths. The first trials were carried out in a carrot test field located in Villena (Spain) to detect plants infected with *Candidatus Liberibacter* solanacearum. The crop was inspected every month from sow to harvest. Labels were placed on 100 plants to guarantee their individual identification in the images. During the harvest, these plants were collected separately, identified and analysed in the laboratory using molecular techniques in order to determine whereas they were infected or not. Several maps of the field have been created using spectral indexes at a very high resolutions between 0.5 mm/pixel and 2.5 mm/pixel depending on the camera.

Keywords: Field robot, computer vision, multispectral imaging, proximal sensing, asymptomatic detection

1. Introduction

Candidatus Liberibacter solanacearum (CaLsol) is a bacterium that affects the phloem of plants. The transmission of the disease occurs mainly through insect vectors, although it can also occur by grafting or seeds (Antolinez et al., 2017). In Europe it is causing damage mainly in carrots. In Spain, the bacteria are distributed in several areas, especially affecting carrots and have already been detected in some potato plantations, although the bacteria can also affect plants such as celery, parsnips, parsley or fennel. Another haplotype also affects tomatoes, peppers, aubergines, tobacco, good grass or mint.

The most prominent symptoms in these plants are the wrinkling of the leaves, generalized chlorosis, purplish discoloration and atrophied growth of shoots and roots. The disease in the aerial part of these crops causes growth retardation, erection of the new foliage, generalized chlorosis, purpurea coloration of the foliage with basal cupping of the leaves and interruption of fruit formation. However, symptoms may be confused by those caused by other pathogens (i.e. phytoplasma, *Spiroplasma citri*) and, in other cases, while the fruits are affected the aerial pat remain asymptomatic which makes difficult their visual detection. Hence, it is necessary to carry out frequent sampling and laboratory analysis to determine the presence of the disease in the plants, which is difficult and expensive to do it on a large area of the crop.

The use of remote sensing in precision farming can help to study a large spatial extent and with high resolution to detect plant diseases (Baylis, 2017). These techniques have evolved over the last three decades and can be performed at different scales, depending on the area to be monitored as well as the spatial and spectral resolution required (Martinelli et al., 2015). At leaf level, spectral information can be collected at a high spatio-temporal resolution, and can be achieved using hand sensors or mounted on agricultural vehicles. On the other hand, the reduction of prices and miniaturization make unmanned aerial systems (UAS) increasingly popular for rapid monitoring at crop level (Vicent and Blasco, 2017). This work aims to help in the early detection of crops infected by the CaLsol at plant and crop level, using high resolution proximal sensing sensors mounted on a electrical platform designed and developed for this purpose.

2. Materials and Methods

2.1. Field robot and experimental crop

For this purpose, an electric terrestrial vehicle (Fig. 1a) remotely operated has been created to incorporate on board a full set of sensors for monitoring entire fields. A telescopic system allows adapting the width of the robot to the needs of the field in a range between 100 and 200 cm because the geometry of the crop allows the wheels to circulate only by a few lines separated by a certain distance that can vary from one crop to another. On the other hand, this system allows to reduce its size to be transported in a van. The robot and all the sensors are powered by a battery while an electric generator is used to illuminate the scene using four light halogen lamps, each of one located in the four corners of the scene. These are used to capture the images under controlled conditions, preventing the negative effect of natural changing conditions and also the direct sun lighting. Aligned at the top-middle of the chamber are the sensors to capture all the inspection area.

To capture the images at determined distances avoiding gaps and overlapping, a programmable system was developed to synchronise the trigger of the cameras with the advance of the vehicle using two optical encoders coupled to each drive wheels. The signal from optical encoders was also used to assist in the guidance of the vehicle through a proportional–integral–derivative controller (PID). In addition, an application was developed to run in the industrial computer and control the triggering and image acquisition of all cameras during the field tests. In addition, a GNSS receiver (Hiper SR, TOPCON Corp. Japan) with RTK correction was installed in the vehicle, allowing geolocation with an accuracy of around 1 cm to identify each of the crop plants in the images.

The experiments have been carried out in a carrot crop (Figure 1b) located in Villena, Alicante (Spain) for two years. Red lines delimit the monitored area containing 27 cultivated rows. Inside this area, some patches were treated with different products to prevent the infections in the area delimited by the yellow lines in Figure 1b. Each of these 27 cultivated rows was composed of three lines of plants with a total width of 1.5 m approximately that were inspected at the same time. In each of the two seasons tested, six inspections of the whole area were carried out, one every month during the crop cycle from the sowing to the harvesting (June-October) to observe the evolution of the plants during their growth and try to detect the infection as early possible. During the last survey of the field, 100 plants were marked using red discs to be later identified in the images. These plants were collected separately and taken to the laboratory to undergo a spectral analysis with a spectrometer (200 to 1800 nm) and with a hyperspectral camera (400 to1000 nm), and also using an ultraviolet induced fluorescence imaging system. Finally, and a molecular analysis using specific real-time polymerase chain reaction (q-PCR) was performed to determine the presence or absence of infection in the leaves and use these plants for reference in the further creation of statistical models.

a) b)

Figure 1. a) Remote-guided vehicle; and b) carrot crop in Villena, Alicante (Spain)

2.2. Sensors

The sensors mounted in the terrestrial vehicle (Fig. 2) include three DSLR (Digital Single Lens Reflex) cameras (EOS 600D, Canon Inc, Japan), two of them modified to capture images in near infrared (NIR) from 700 to 1000 nm, and blue NDVI (normalized difference vegetation index), a thermal camera (A320, FLIR Systems, USA) and a multispectral camera (CMS-V, Silios Technologies, France) capable of capturing eight monochromatic images in 558, 589, 623, 656, 699, 732, 769 and 801 nm. The DSLR cameras allow to capture images of the crop with a resolution of 0.5 mm/pixel and the thermal and the multispectral camera could obtain images with a spatial resolution of 2.5 mm/pixel. All the cameras were configured to capture images synchronised with the advance of the vehicle about one image per meter with integration times less than 4 ms to avoid moving or blurry images.

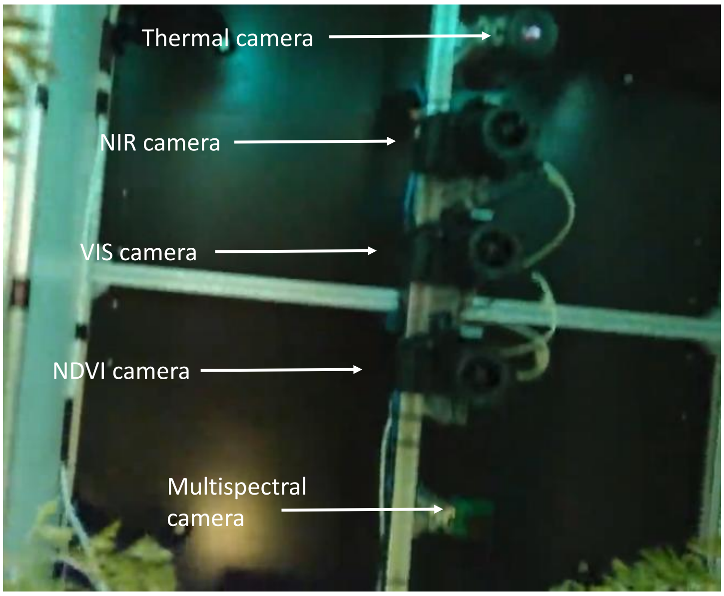

Figure 2. Image captured from the crop side, showing the sensors on board from the ground

3. Results and Discussion

The main result at this stage is the creation of a robotic solution, remotely operated that can transport different proximal sensing equipment to inspect horticultural crops, illuminating the scene to prevent direct solar radiation. The robot advances smoothly at a very accurate speed which allows the creation of precise high resolution maps of the crops. Starting from the images collected by each camera of the whole crop, images in different bands of each of the rows cultivated are made. The images are being analysed to create maps showing different spectral indexes (Zarco-Tejada, 2012) from the images captured in different spectral bands (Fig. 3).

The results of the field analyses in these two years of trials show no clear signs of CaLsol in the spectral information acquired during the monitoring period. However, no information was obtained from negative samples to be able to compare in the images since the great majority of the samples presented positive results in the detection of the CaLsol bacteria. The results of the laboratory analysis (both, spectral and molecular) together with the analysis of these specific plants captured in the field, will serve to create maps of crop with different vegetative indexes showing potential infections that will be contrasted with the information collected by the Bacteriology Unit of IVIA and visual inspection provided by the technicians of the cooperative Agricola Villena.

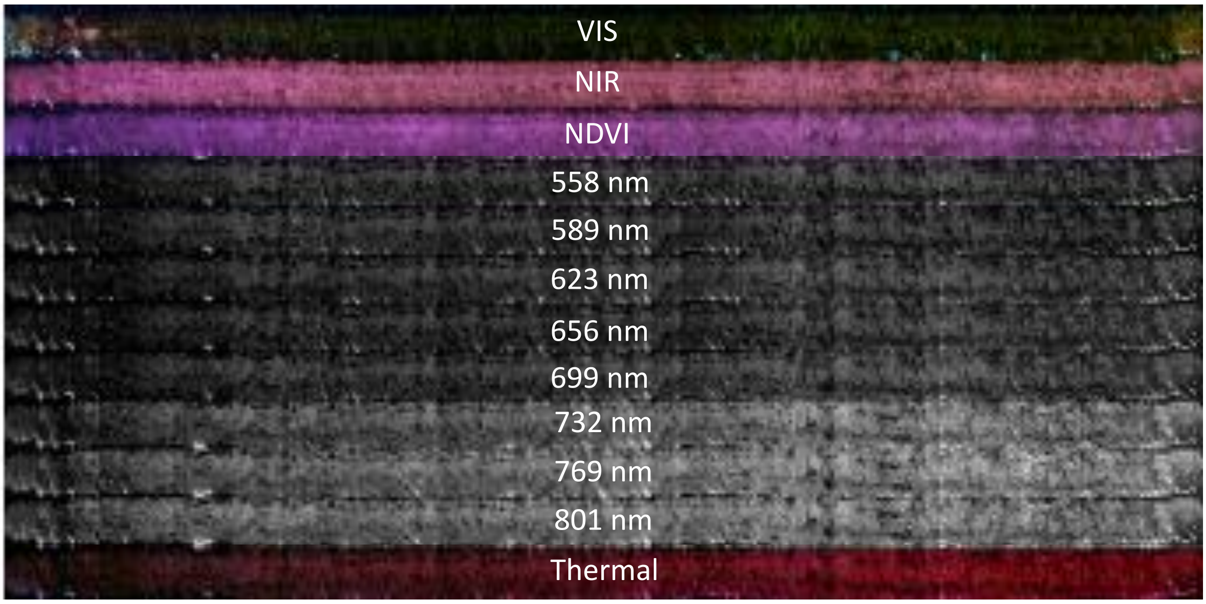

Figure 3. Image of one of the rows of the crop captured in different spectral bands

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References

Antolinez CA, Fereres A, Moreno A. (2017). Risk assessment of '*Candidatus Liberibacter* solanacearum' transmission by the psyllids Bactericera trigonica and B. tremblayi from Apiaceae crops to potato. Scientific Reports 7, Article number: 45534

Baylis A (2017) Advances in precision farming technologies for crop protection. Outlooks on Pest Management, 28: 158-161

Martinelli F, Scalenghe R, Davino S, Panno S, Scuderi G, Ruisi P, Villa P, Stroppiana D, Boschetti M, Goulart LR, Davis CE, Dandekar AM. 2015. Advanced methods of plant disease detection. A review. Agronomy for Sustainable Development 35: 1-25.

Vicent A, Blasco J. (2017) When prevention fails. Towards more efficient strategies for plant disease eradication. New Phytologist, 214: 905-908.

Zarco-Tejada PJ, González-Dugo V, Berni JAJ. (2012) Fluorescence, temperature and narrow-band indices acquired from a UAV platform for water stress detection using a micro-hyperspectral imager and a thermal camera. Remote Sensing of Environment, 117: 322-337