Preliminary approach for the detection of olive trees infected by *Xylella fastidiosa* using a field robot and proximal sensing

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Abstract

A small field robot was designed and built within the framework of the H2020 project *Xylella fastidiosa* Active Containment Through a Multidisciplinary-Oriented Research Strategy (XF-ACTORS). The robot is remotely driven and provided with different proximal sensing equipment for the early detection of Xf in olive groves, including thermal, colour and multispectral cameras, and a 2D laser scanner (LiDAR) to obtain the 3D structure of the crop. The equipment is completed by a GPS to geolocate the data obtained and an IMU (inertial measurement unit) to correct the data captured by the LiDAR. An industrial computer triggers the sensors and controls the data acquisition, which is synchronised with the advance of the robot by means of a pulse encoder coupled to the axis of the motor. Then, crop maps can be created off-line after the analysis of the collected data to show graphically potential *Xf* infection in the trees. Owing to the height of the olive trees inspected, the cameras were placed on a platform that can be elevated up to 200 cm. Two batteries power the electric motors attached to the wheels, thereby allowing a continuous inspection for approximately six hours (a field of about 4 ha). A series of tests have been carried out in an olive orchard showing slight symptoms of *Xf* infection in the region of Apulia, southern Italy. During the first tests, the robot inspected each row in both directions with the cameras pointing to one side, so as to inspect all sides of the trees. The tests were mainly focused on the development of the mechanics, navigation systems, sensors and data acquisition. Synchronised and geolocated images of the whole crop were also captured with the cameras in different climatic conditions, as well as with the laser scanner for later comparison to the in-situ observations.

Keywords: Robotics, computer vision, multispectral imaging, Lidar, asymptomatic detection

1. Introduction

Xylella fastidiosa (*Xf*) was first detected in Italy (Apulia region, southern Italy) in 2013 (Martelli et al., 2016) and it has expanded rapidly throughout the region causing severe damage to olive crops. The detection throughout Corsica (France) and in southeastern France and the more recent detections in Mallorca (2016), Alicante (2017) and Madrid (2018) in Spain, has greatly increased the awareness of the threat that this pathogen poses to European agriculture and environment (Purcell, 1997). As a consequence of the *Xf* outbreak in Italy affecting mostly olive trees, almost the entire province of Lecce (Apulia Region) has been demarcated as "infected area" and only containment measures are enforced. The project XF-ACTORS (EU H2020 GA Nº 727987) faces the problems from a multidisciplinary research approach. Among the solutions proposed, it is included the setting up of proximal and remote-sensing tools for early diagnostic and surveillance programs.

The representativeness of diagnostics relies strongly on proper sampling design, both at the field and the individual plant level but large spatial extent and fine resolution can only be achieved through extensive testing at relatively high cost (Vicent and Blasco, 2017). Then, the use of remote sensing to map the distribution of plant diseases has evolved considerably during 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). While manned aircraft remains the only alternative to obtain maps at larger scales with optimum spatial and spectral resolution for the early detection of disease outbreaks (Calderón et al., 2015), at the plant level the spectral information can be gathered at high spatio-temporal resolution using sensors mounted on regular agricultural vehicles.

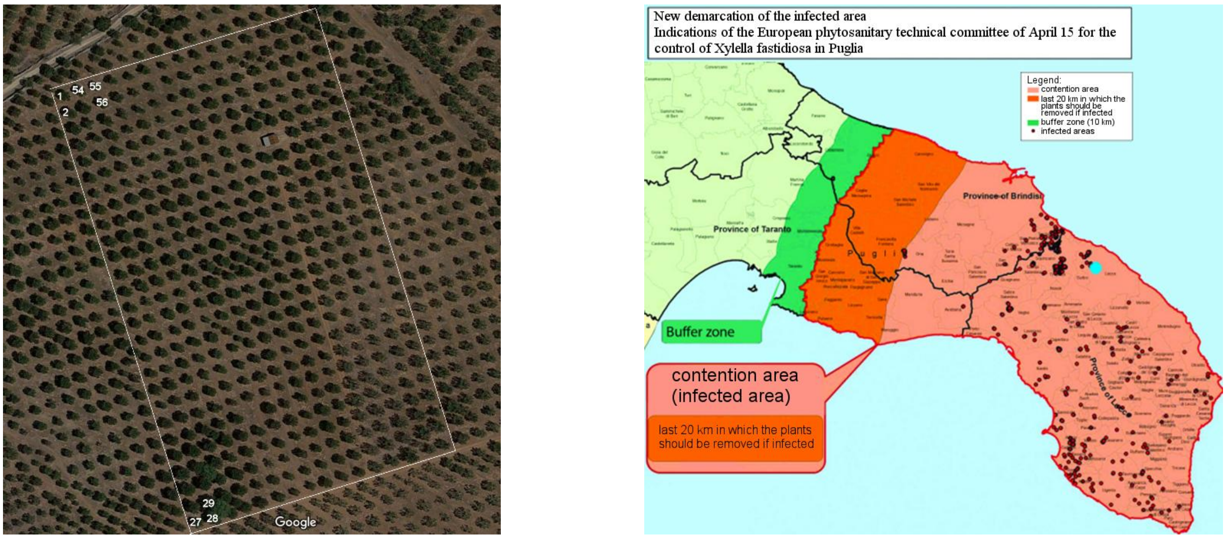
This work presents a small field robot built for the early detection of *Xf* in olive crops. The robot is remotely driven and provided with different proximal sensing equipment including thermal, colour, multispectral and hyperspectral cameras, and a 2D Laser Imaging Detection and Ranging (LiDAR) to obtain the 3D structure of the crop. The equipment is completed by a Global Positioning System (GPS) to geolocate the data obtained and an Inertial Measurement Unit (IMU) to minimise the negative influence of moving on uneven ground.

2. Materials and Methods

2.1. Terrestrial vehicle

The small robot has been designed and constructed to carry on board the sensing equipment and inspect a field with olive trees from 5 to 6 meters high. A required restriction of the robot is a relatively small size, so that it can be easily transported in a van, thereby its maximum size is 100 x 60 cm. Apart from the sensing equipment, it mounts two easily replaceable gel batteries that power two electrical motors, an industrial computer, a folding screen, and all the electronics required to operate the robot and capture synchronised and georeferenced data. The batteries last >6 h when fully charged. It is driven wireless with a remote control. A platform containing the cameras can be elevated up to 200 cm for better measurement of the highest trees. A programmable system has been developed to synchronise the cameras with the advance of the vehicle, so that images can be acquired at predetermined distances while the robot advances. An IMU unit allows later corrections of the inaccuracies due the irregularity of the ground. The sensors mounted on the robot included two DSLR cameras (EOS 600D, Canon Inc, Japan) one of them modified to obtain NDVI (Normalized Difference Vegetation Index) images, a multispectral camera (CMS-V, Silios Technologies, France) that can obtain simultaneous images in eight different wavelengths (558, 589, 623, 656, 699, 732, 769 and 801 nm), a low cost hyperspectral system (spectrograph Imspector V10, Specim Spectral Imaging Ltd., Finland + camera uEye 5220CP, iDS Imaging Development Systems GmbH, Germany) and a thermal camera (A320, FLIR Systems, USA). All cameras were configured to capture one image per meter synchronised with the advance of the robot.

In addition, the entire grove was scanned using a LiDAR (LMS111, Sick AG, Germany) with an effective sweep angle of 270º and resolution of 0.5º. All data were geolocated using a GPS (Hiper SR, TOPCON Corp. Japan) and corrected trough the data captured by a 9-axis absolute orientation sensor (BNO055, Adafruit learning system, USA). The LiDAR, the GPS and the orientation sensor units were configured to operate in free range, with the highest resolution of each sensor. Thereby, the synchronisation between data from three units was done by means of the time stamp (in ms) provided in the data streams captured by every sensor.



a) b)

Figure 1. a) Experimental olive grove located in the Lecce Province; and b) Demarcations of the infected area in the Apulia Region (Italy) including the indications of the European phytosanitary technical committee on *Xylella fastidiosa*

2.2. Field tests

Two experiments were carried out in the Lecce province in September 2017 and June 2018, in an olive grove known as C20 (Fig. 1a) with a size of 3 Ha. This field is located in the contention area demarcated by the UE (Fig. 1b). The robot was deployed in the field. The robot advanced in one row acquiring the images of the trees on one side and turn back in the same row acquiring the images of the trees in the other side. During the tests, the vehicle crossed the entire field firstly in one direction (vertical) and later in the other direction (horizontal), obtaining images and data of four sides of each tree with all the sensors. On the drive up, the vehicle imaged one row of trees, imaging an adjacent row on its way back. The first tests (September 2017) were used to fine-tune the robot, electronics, setting up and programming all sensors, collecting preliminary data and improve autonomy and ease of handling, while the latest tests (June 2018) while the second tests were already carried out to collect data on the orchard structure and try to detect the presence of the infection in the trees. Before, during and after the inspection, images of a standardised colour checker (ColorChecker SG Chart, X-Rite Inc, USA) and a white reference target (Spectralon 99 %, Labsphere, Inc, NH, USA) where acquired for further correction of the images. The sensors worked correctly and the images that were obtained from the entire field are awaiting analysis.

Moreover, a visual inspection of each tree was done based on the severity of its symptoms. Each of the four sides of the tree that were then monitored by the robot were measured on a scale of 1 (no symptoms) to 5 (dead tree). However, as the field is currently active, the farmer uses to remove the branches in poor condition so the visible symptoms do not always correspond to the actual degree of infection. This is a critical problem to obtain reference data on early detection of asymptomatic trees infected but does not affect the detection of the symptoms when present. Apart from measuring the visual symptoms, some trees were analysed using techniques of molecular biology to accurately detect the presence of the infection.

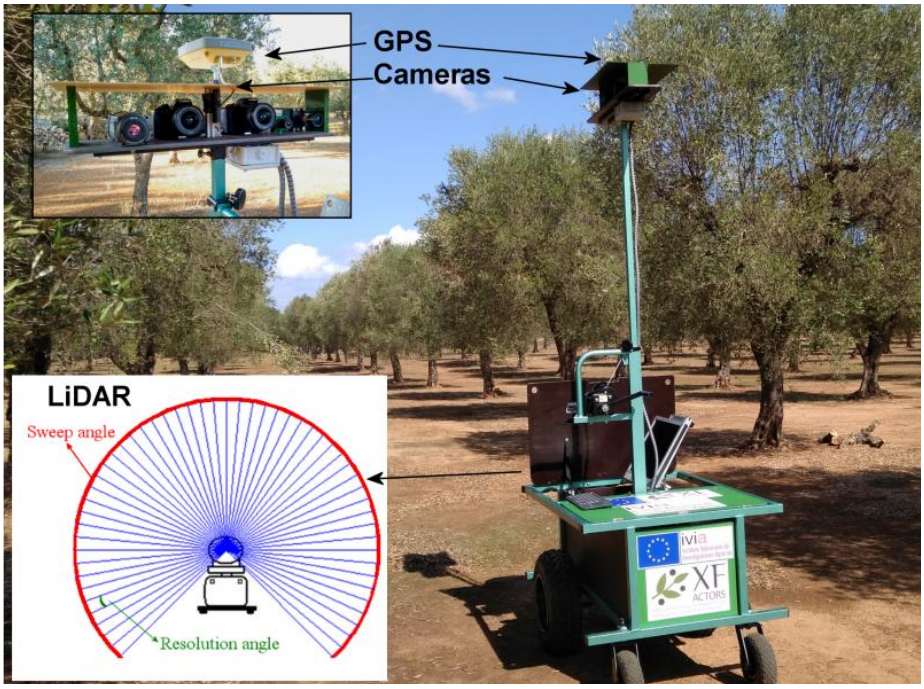


Figure 2. a) Remotely driven robot with details of the sensors mounted;

3. Results and Discussion

The robot work properly during the tests, being capable of continuously inspect the whole field and was able to inspect the entire field without interruptions capturing more than 77000 images. All sensors worked well capturing data synchronised with the advance of the robot. The trees were labelled following a matrix strategy, that is, in rows and columns corresponding with the navigation path of the robot, and the images captured associated to their corresponding tree. At this time, all the images captured are still under analysis. The data from LiDAR, the GPS and the IMU sensors, were stored in ASCII format, recording one file per row/column scanned. The LiDAR coordinates, originally in millimetres in a cylindrical coordinate system, were converted to meters in a Cartesian coordinate system and subsequently geolocated with the GPS reference using the WGS 84 / UTM coordinates system in the 34T zone. Later, these coordinates were corrected by means of the IMU unit using the pitch, yaw and roll angles to minimise the impact of the irregularities of the ground on the movement of the robot. Finally, Point clouds describing tree rows from opposite viewing angles were then merged to generate the full 360˚ rendering of the trees as shown in Fig. 3. The synchronisation of the both LiDAR sensor and GPS and IMU units was done by means of the time stamp in the data streams captured with a time resolution of one millisecond. All the software to extract and process this information has been developed in MATLAB (8.5 R2015aSP1, The MathWorks Inc., USA).

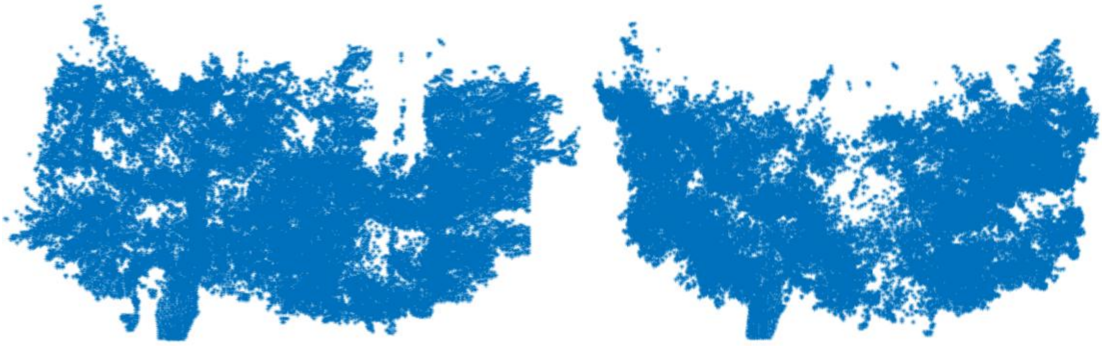


Figure 3. Three-dimensional points in UTM coordinates both representing two different views of one of the olive trees in the scanned field

After the 3D rendering of the trees, all the points of each tree in the field were projected into the corresponding UTM zone as a top view of the field, and the contour (profile) of the top view of every tree, calculated as the convex hull, has been extracted. This profile is intended to be used to calculate the leaf area density (LAD) (1), the leaf area index (LAI or cumulative LAD) (2) and the normalised difference vegetation index (NDVI) (3). Next, the LiDAR-based renderings of the trees will be combined with spectral indices retrieved from the passive cameras.

Figure 4 shows the projection of several trees (top views) in the UTM zone superimposed on a Google satellite view of the field. The red colour has been chosen in order to highlight the dots projection from the satellite picture.

Figure 4. Projection of the 3D scanned points superimposed on a Google satellite view of the field.

$$LAD = u(z) \tag{1}$$

u=surface density coefficient of a slide foliage;
z=specific height of the slide in the tree foliage;

$$LAI(z) = \int_{z=0}^{h} LAD(z)dz; \tag{2}$$

In m^2m^{-2} units, where *h* goes from 0 to canopy height;
LAD(z)= surface density coefficient;

$$NDVI = \frac{NIR - VIS}{NIR + VIS} \tag{3}$$

NIR= near infrared reflectance;
VIS=visible reflectance;

Acknowledgements

This work was partially supported by funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 727987 *Xylella Fastidiosa* Active Containment Through a multidisciplinary-Oriented Research Strategy (XF-ACTORS)

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