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On the design of a Mechatronic Mobile System for Laser Scanner Based Crop Monitoring

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***Abstract*—Modern agriculture sees an increasing diffusion of information systems to support the farmer for a more accurate and efficient activity, in particular through a continuous and global environmental, operational and crop monitoring.**

Focusing on the crop monitoring, i.e. the direct observation of the tree canopy in order to obtain a series of agronomical information, new and effective sensors, together with an integrated mechatronic approach and mobile robotic platforms, can be the ingredients for future smart and effective solutions.

In this work, following the approach of Sanz-Cortiella et al. and Lee et Ehsani [1], [2] for ground level tractor-based scanning, a first attempt concerning the development of a LIDAR sensor integrated in an autonomous or tele-operated mobile robot equipped with position and inertial sensors is presented. The purpose of the work is to evaluate the feasibility and performance the of the idea that consists in the monitoring, scanning, digital detection and recognition of both the canopy and the fruit situation in orchards, by means of an emulated environment. Preliminary experiments in an emulated environment have been conducted with the aim of using these sensors together with autonomous robots in agriculture.

I. Introduction

The modern and effective management of orchard and vineyards passes through a detailed information collection about the morphological characteristics of the canopy; this is made not only in function of the sustainable use of pesticides, but also for the proper use of resources to maintain an optimal vegetative-productive balance on the plant. These aspects are of the main importance for obtaining high yields of quality and healthy products. Indeed, the geometry of the canopy is strongly correlated to the growth of the plant and its productivity [2] and this information has been used by various authors to make predictions about production [3], [4], for applications of fertilizers in citrus [5], water consumption [6] and in measuring the density of biomass [7].

The structure of the fruit trees canopy varies greatly depending on many parameters such as the vegetative stage, the plant specie and the type of cultivation; the application of pesticides without taking into account the structure of the orchard/vineyard is in contradiction with the general relationship that the pesticide released in environment and the foliar deposit should be in the ratio 1:1, regardless of the plant size and density of the canopy [8]. If made, this has an impact on the relationship between the amount of product issued by the atomizers and the residue deposited on the culture of reference [9], [10]. The objective of pursuing this principle leads to a considerable increase in the effectiveness and efficiency of the treatments, thereby reducing the amount of plant protection products requests, in accordance with the latest European trends (European Parliament. Directive2009/128/CE), and limiting the problems due to environmental contamination [23], [24].

The canopy characteristics can surely be manually measured; then, by calculating the average of height and width of the crop, it is possible to estimate the total volume of the crown in the spin, the so-called TRV - Tree Row Volume [m^3]. This parameter has been widely used to determine the appropriate amount of product to be distributed, but these manual measurements require a homogeneous structure and it should be extrapolated from different measurements inner the cultivated area [25], [24], [26]. Thus, this method is very expensive in terms of resources and time, and not completely reliable if applied to not homogeneous plots of land. Also the leaf area index (LAI) and the total leaf area can be measured manually: this measurement is generally carried out through a destructive method, i.e. the total defoliation of the entire area of the crop sample and subsequent laboratory measurements on each single leaf surface, resulting in a time and resources wasteful method. Moreover, also in this case, the values are obtained by taking into account only a specific area and possible estimation errors should occur since they need to be extended to the entire area resulting from the lack of information.

At today, thanks to the availability of smart and new sensors, these manually performed actions can be automatized and made more efficient both in terms of precision and required time thanks to the application of mechatronic and proximal and remote sensing approaches. In this regard, the Lidar (Light Detection And Ranging) is one of the most promising technologies.

A. Lidar

The Lidar is a remote sensing technology that uses a laser pulse to determine the distance of an object or a surface. This is achieved by measuring the *time-of-flight*, i.e. the elapsed time between the emission from a laser pulse source at a specific wavelength and the reception by a receiver of the backscattered light. The result gives a point cloud that, post-processed, can be exploited for the construction of a 3D image. The LIDAR uses short wavelengths, typically those in the visible and near-infrared but also in the ultraviolet, that allow it to detect and obtain information even on very small objects like particles released from livestock in atmosphere [11] or volcanic ash [12], [13], [14]. This feature makes it ideal for measuring non-metallic objects, which represent a problem in radar-measurements since it works with longer wavelengths, i.e. microwave. Indeed, in such a high wavelengths, metal objects produce a good reflection while non metal ones, such as the tops of the trees, produce very weak reflections resulting almost invisible.

The LIDAR technology has found employment in different sectors both in a static and mobile applications.

In particular, thanks to the development of the global positioning system (GPS), it has found new application such as for mapping coastlines, coral reefs and bathymetric surveys [15], [16], [17], as well as for studying the rivers morphology [18].

Today, the use of this technology spaces in many areas; for example, it has been used to monitor and better understand the dynamics and sedimentation processes after the retreat of the glacier [27], for measure the mass balance and dynamics of a glacier [28], or for simply make a mapping [29]. In seismology, it is used to study and monitor the gradual shifting of tectonic plates along a fault [30], [32]. Forestry has become another important field of application of LIDAR technology: it is used to perform mapping of forest biomass [33], for estimating the bushy biomass in Mediterranean areas [34] and for mapping areas at risk of fire into the forests [31].

Various attempts and experiences can be found also in agriculture where the sensor is used in association with a land mobile equipment, e.g. tractor, to collect and provide data over the zone examined. Rosell et al.[19] concluded that a LIDAR system is capable of measuring the fruit plants geometrical characteristics with sufficient precision to satisfy the majority of agronomic practices. In viticulture this technology has been used to determine the volume of perennial biomass of Vitis vinifera to facilitate the calculation of annual biomass production, accumulation and carbon cycle within the vineyard [20], but also for the characterization of the drift during the pesticide treatment [21].

In robotics, the Lidar technology is being used for the perception of the environment as well as object classification, e.g. in Surface Localization and Mapping (SLAM) activities.

B. Aim of this work

In this paper, the Lidar technology in conjunction with an (semi-)autonomous mobile robot has been used to create a new robotic system application able to be tele-operated or navigate inner an orchard for monitoring activities. Indeed, as previously pointed out, on one hand the Lidar technology has started to be adopted in agriculture in conjunction with tractor motions, on the other hand mobile robots have usually exploited the Lidar sensor for different purposes and not, as here, for 3D image reconstruction and volumes and fruits identification.

The purpose of the work is, then, to develop a tele-operated or autonomous robotic system able to carry out an intra-row navigation and a 3D shape reconstruction to obtain a better estimation of the Tree Row Volume parameter, usually estimated by manual measurements, and a more efficient working activity since both the tractor and the farmer can be employed in other tasks.

Fig. 1. Lidar SICK LMS111

TABLE I
LIDAR SICK LMS111 CHARACTERISTICS

Features	LMS111
Max Range	20 m / 18 m
Scanning Angle	Max 270^o
Angular resolution	0.5^o / 0.25^o adjustable
Scanning frequency	50 / 25 Hz
Response time	20 ms / 40 ms
Error (stat)	12 mm typ.
Sender	Pulsed laser diode
Light source	Infrared (905 nm)
Operating temp	-30^{o}C to 50^{o}C

II. MATERIALS AND METHODS

A. LIDAR SICK LMS111

In this work, a LIDAR sensor SICK LMS111 has been used (Fig.1). The LMS111 falls within the short-range devices, has a maximum radius of 20 meters, a working-angle of 270^o and it is suitable for outdoor applications. Table I shows the device main technical characteristics.

B. NI Mobile Robot

In order to develop an emulator system able to travel in semi-structured environments in an autonomous way and collect the required data, the Lidar sensor has been mounted on a mobile platform. The chosen system is a four-wheel mobile robotic platform equipped with ultrasonic and inertial sensors.

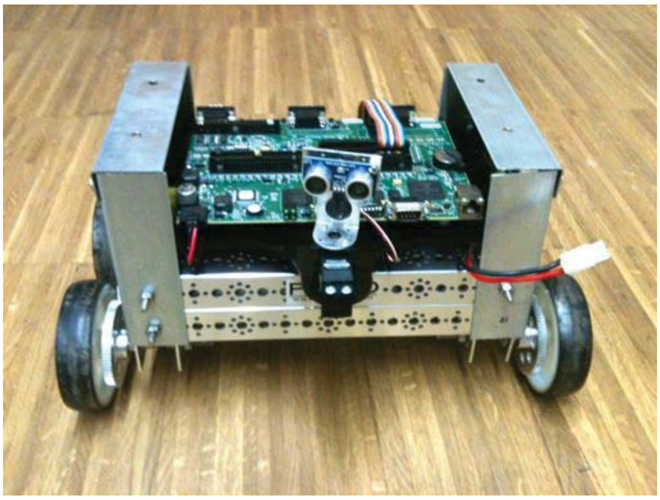


Fig. 2. NI Labview Robotics Starter Kit

Such an autonomous or tele-operated system can be adequately controlled to follow a direction with a predefined velocity.

The mobile system is the NI LabVIEW Robotics Starter Kit robot that is equipped with a NI Single-Board RIO-9632 [22], Fig. 2, that can be linked and programmed by means of the Labview Robotics module.

The NI sbRIO-9632 embedded control and acquisition device integrates a real-time processor, a FPGA, and I/O on a single printed circuit board (PCB). A 400 MHz industrial processor and a 2M gate Xilinx Spartan FPGA are mounted. The sbRIO-9632 offers a -20 to 55 C operating temperature range, thus can be suitable for outdoor applications, and nonvolatile memory for storing programs and data logging, 256 MB. This solution allows to support the Lidar sensor and to follow a straight line or a row inner a vineyard at a constant speed, or to modulate speed to search the optimal response and be able to assess which appears to be the more satisfying. To develop the control software, the Labview software has been exploited.

C. Software

Two separate software systems have been adopted for the defined purpose. One one hand a system able to interact with the Lidar and talk and send the acquired data to a host PC has been developed; on the other hand, an independent program has been set-up for the control of the robotic platform.

Sopas Engineering Tool (ET): the Lidar device can be configured with the software SOPAS ET that allows to change the parameters of the device, as well as those of scanning according to the needs. The acquired data are saved in a .log file that can, if properly transmitted, be automatically post-processed for the user purposes.

A second software, the Hercules setup utility, has been selected for the information communication and sending, in particular time, luminance and distance.

The mobile robotic platform has been programmed and controlled through the NI LabVIEW Robotics Module software that allows to develop and deploy a robotics application using LabVIEW. The implemented code allowed the robot to move autonomously along a linear path and avoiding possible obstacles.

Fig. 3. Selected objects for the chosen test-case

The acquired data, obtained by the sensors, are in hexadecimal format string. Through a Matlab script ad hoc developed, they are post processed and managed to obtain the desired information and 3D reconstructed figures.

D. Experimental Set-up and scenario

In order to perform the scanning measurements, the Sick LMS111 LIDAR sensor has been mounted on a horizontal plane, parallel to the ground, which was in turn fixed above the mobile robot. In this way it was possible to scan an artificial wall, which has the aim to simulate a wall inside a foliar orchard. Tests have been performed in a dynamic way, i.e. they have been executed in motion and not between steady-state configurations, in order to reconstruct in a lab environment a possible realistic scenario.

The measurement tests have been set by means of different scenarios. For instance, a vertical wall, homogeneous and uniform, i.e. a cork panel, on which were hung four different objects both in terms of type and size have been evaluated. They are, Fig.3:

- an apple, with a diameter of 8 cm and a height of 7 cm;
- a lemon, with a diameter of 7 cm and a height of 8 cm;
- a perfect polystyrene sphere (diameter 10 cm);
- a rectangular cardboard box of height 13 cm, length 19 cm and depth 17.5 cm.

The objects were placed on the panel at a height and at a known distance, Fig.4.

The LIDAR sensor placed on the self-propelled vehicle was in turn located at an height of 28 cm.

Straight trajectories parallel to the wall at three different distances, i.e. 50 cm, 100 cm and 150 cm, have been performed to evaluate the different responses of the sensor to the distance parameter. Different sampling frequencies and angular resolutions, i.e. 25-50 Hz and 0,50^o-0,25^o have been tested.

For each acquisition configuration and wall distance, four acquisitions have been performed; moreover, different down-sampling conditions have been applied in order to evaluate

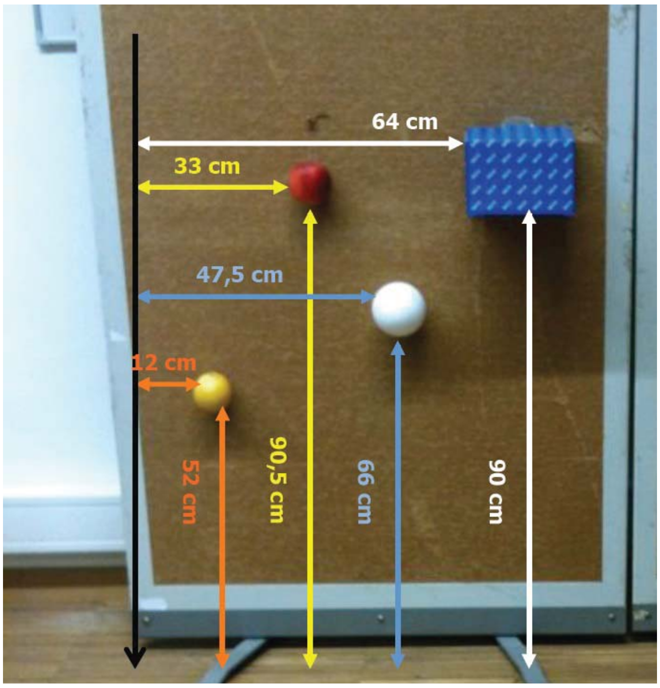


Fig. 4. Test-case scenario

Fig. 5. Test-case scenario with an apple branch

the proper acquisition frequency. The robot sensors have been exploited to measure the traveled distance and the robot position and orientation with respect to time in order to build the 3D plot of the scenario.

In addition, in order to better emulate a real environment, apple branches are currently used as test-case, and both the distance and luminance information are used to discriminate between fruits, leaves and wood, Fig.5.

Currently, new outdoor tests in an orchard are planned and the mechatronic system is under calibration for evaluating the performances in a real environment.

III. Tests and Results

All the acquired data have been post-processed and put in a plot form by an ad-hoc developed Matlab software.

In this section, some significant results that lay the basis for the future development of the autonomous robotic platform for crop monitoring are shown.In addition, some comparisons related to perspective, surface distance and traveling velocities are made.

In Fig.6 a scanned side view (Z axis: height - Y-axis: distance robot-panel 0,50 m) with acquisition frequency 50 Hz, resolution angle 0.5^o and robot speed 0.1 m/s is shown. The object boundaries are clearly visible and recognizable; the peaks correspond to the actual scanned diameter of the spherical objects while regarding the cardboard box, the depth is approximately respected. The real shapes are superimposed: the orange ellipse represents the lemon, the green the ball while the rose one the apple and the yellow rectangle represents the box. The discrepancy can be explained by the fact that the acquisition has been carried out in a bottom-top condition, thus the laser beam intercepts objects not at right angles, offsetting slightly the data. Fig.7 shows the same acquisition but from above the panel. Peaks of different scanned objects are clearly distinguishable. In this case, the measured dimensions reflect the real objects, given that the length of the arrows color is proportional to the size of each object.

If different down-sampling are applied, the lower allowable frequency, i.e. the one for which the objects can be adequately recognized, can be estimated. In Fig. 8, a comparison between different frequencies and same angular resolution (0.5^o), distance (1 m) and speed (1m/s) are shown. The sampling frequency in the different graphs has been 50, 5, 2 Hz respectively. By looking at the graphs, it can be easily appreciated how, with a 5 Hz frequency, thus one sample each 0.02 m, there is still the possibility to have a sufficient amount of data for recognizing the different objects under evaluation. Taking into account different traveling velocities, up to 0.5 m/s, it can be assumed that a sampling frequency greater than 25 Hz should be adopted for a proper shape recognition.

IV. Conclusion and Future Work

In this paper, a first approach for the development of a LIDAR sensor integrated in an autonomous or tele-operated mobile robot has been presented. The idea consists in the

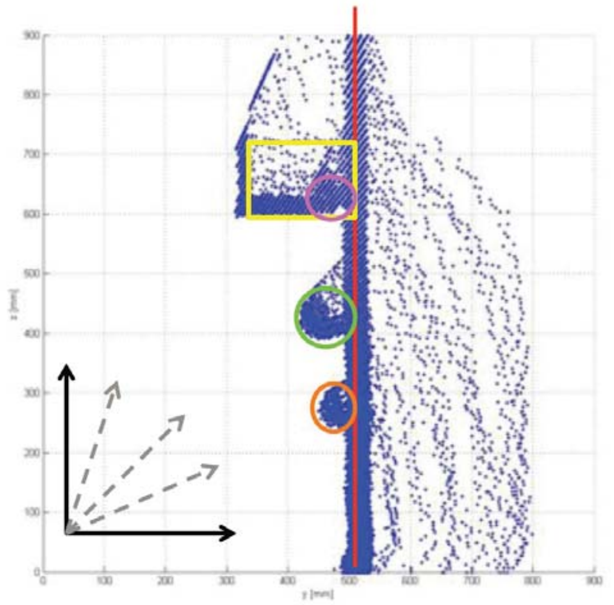


Fig. 6. Test-case scenario: acquisition at 50 Hz, 0.5^o, 0.1 m/s, 0.50 m distance; side view

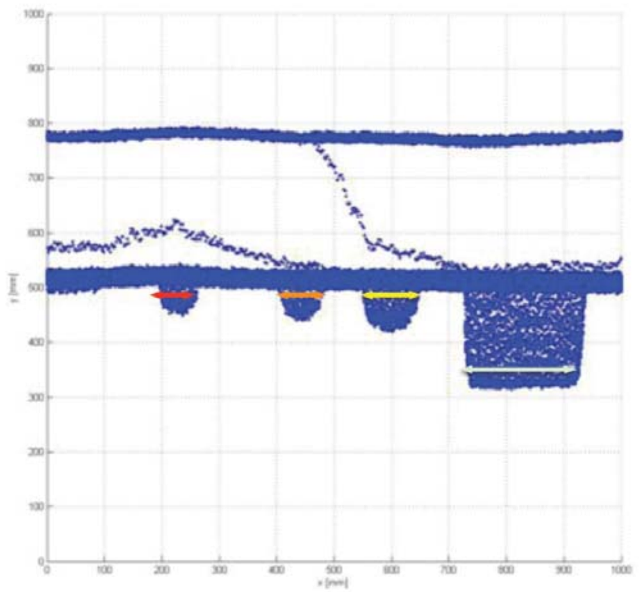
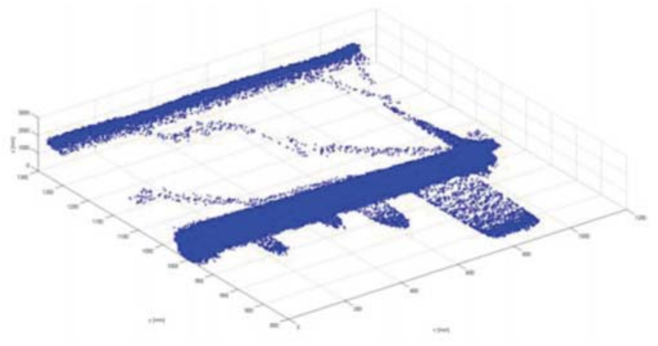
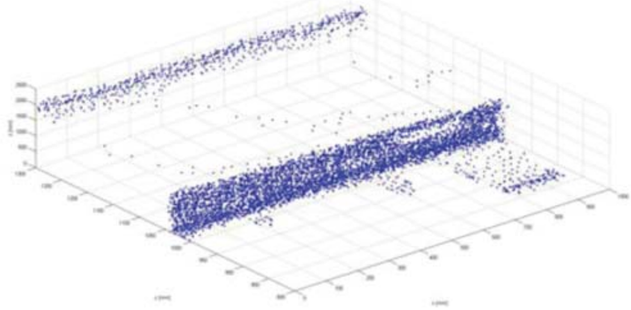


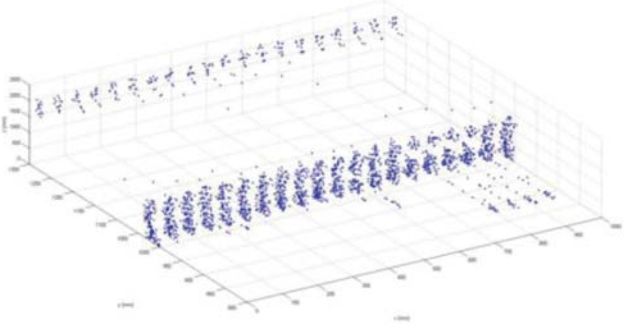
Fig. 7. Test-case scenario: acquisition at 50 Hz, 0.5^o, 0.1 m/s, 0.50 m distance; top view



(a)



(b)



(c)

Fig. 8. 3D plot at different sampling frequencies: 50, 5 and 2 Hz

monitoring, scanning, digital detection and recognition of both the canopy and the fruit situation in orchards, in an emulated environment, with an autonomous robotic system. A four-wheel mobile robotic platform programmed by LabView through a FPGA within a 2D LIDAR able to scan 270^o and give information on distance and luminance, has been set-up. The system has been developed by coordinating and synchronizing the two devices and the robot proprioceptive sensors in order to have a consistent monitoring while the robot is moving. Acquired data are sent to a supervisor PC platform where they are post-processed and the 3D shapes reconstructed, plotted and evaluated by means of a Matlab routine. Preliminary experimental tests in a semi-structured environment with different kind of surfaces and shapes show encouraging results and encourage to convey the system on a real scenario.

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