A System for Adjusting the Spray Application to the Target Characteristics

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ABSTRACT

In the ambit of the ISAFRUIT European Project, a sprayer prototype able to automatically adapt spray and air distribution according to the characteristics of the target, to the level of crop disease and to the environmental conditions is under development. In order to identify the characteristics of the canopy target, in terms of size and density, a Crop Identification System (CIS), based on ultrasonic sensors, was studied and realised. First tests carried out in the field, aimed at verifying the repeatability of results and the functioning of the system with different forward speeds (2, 4, 6 and 8 km h^{-1}), have confirmed CIS suitability to detect in real time the features of the target to be sprayed and to enable the adequate regulation of spraying parameters. Further tests are in course to optimise its implementation on the finalised ISAFRUIT sprayer prototype.

Keywords: Ultrasonic sensor, orchard, spray target, volume application rate, Italy.

1. INTRODUCTION

Pesticide application in orchards are often carried out spraying high volume rates of spray mixtures and adopting large air flow rates, mainly using conventional axial fan air-assisted sprayers that have a limited range of options for their regulation, especially concerning spray profiles and air adjustment (Holownicki *et al.*, 2000; Baldoin and De Zanche, 2003; Pergher, 2006). Environmental concerns and rising demands for healthy fruits increasingly lead to the study of sustainable spraying techniques that could optimise pesticide application in orchards by more precise adjustment of spray and air profiles to target characteristics (Solanelles *et al.*, 2002; Marucco and Tamagnone, 2004; Giles and Downey, 2005; Gil *et al.*, 2007; Walklate *et al.*, 2007).

ISAFRUIT (Increasing fruit consumption through a trans-disciplinary approach leading to high quality produce from environmentally safe sustainable methods) is a European Project, promoted within the VI European Research Framework, in which 60 Partners from 16 European countries are involved. The project (www.isafruit.org) started in January 2006 and will end in June 2010. It is featured by a trans-disciplinary approach, taking into account all the processes involved in fruit production and commercialisation, "from field to fork", with special regard to apples. In the ambit of ISAFRUIT, a prototype of air-assisted sprayer able to automatically adapt the spray application according to the characteristics of the canopy target (size and density), to the level of disease present in the crop and to the environmental conditions at the time of spraying is under development.

For the identification and the characterisation of the target, a Crop Identification System (CIS) based on ultrasonic sensors (Giles *et al.*, 1989; Balsari and Tamagnone, 1998; Wenneker *et al.*, 2003; Solanelles et al., 2006; Gil *et al.*, 2007), developed by DEIAFA (Dipartimento di Economia e Ingegneria Agraria Forestale e Ambientale – Università di Torino) and 3B6 Sistemi Elettronici Industriali company, will be implemented on the final version of the ISAFRUIT sprayer.

The analysis of the echo signals returning from the vegetation target, makes it is possible to assess the size of the plant (canopy thickness) and an index value related to the vegetation density: This parameter mainly depends on the number of leaf layers, on the leaf size and on the canopy structure which is linked to the training system.

Preliminary work, described in this paper, was targeted to evaluate the functioning of the sensors in field conditions, in order to verify their suitability for the scope.

2. MATERIALS AND METHODS

A first set of tests was carried out in an apple orchard with the aim to assess the ability of the sensor to detect the target size and density, to compare the responses of the sensor working at different forward speeds and to check for eventual interferences between the ultrasonic sensors working on the same sprayer side.

The ISAFRUIT sprayer prototype is being developed on the basis of a Hardi Arrow air-assisted sprayer featured by a polyethylene main tank of 1000 l capacity, a double radial fan (540 mm diameter), and equipped with a special air conveyor delivering the air to 16 individual air spouts (8 per each sprayer side) by means of plastic hoses (Fig. 1).

Figure 1. General view of the ISAFRUIT sprayer prototype.

The sprayer design allows the nozzles to be positioned on the air spouts that are fixed on vertical supports; therefore, it enables to reduce the average distance between nozzles and canopy target. Moreover, the vertical spray profile can be subdivided in three bands, corresponding to different plant heights (Fig. 4B).

On each sprayer side, six of the eight spouts are equipped with two sets of 4 nozzles: 4 conventional flat fan nozzles and 4 air induction flat fan nozzles (Fig. 2). The remaining two air spouts (without nozzles) are mounted between the others in order to facilitate spray penetration into the canopy.

Figure 2. Detail of one single air spout equipped with conventional and air induction nozzles.

The sprayer prototype, intended for spray application in apple orchards, will be used with three different systems:
1) a Crop Identification System (CIS), based on ultrasonic sensors, enabling to recognise the morphology of the target and to adapt the spray distribution to the vegetation size and density;
2) a Crop Health System (CHS), based on optical sensors, aimed at assessing the health status of apple leaves in order to modulate the amount of applied spray;
3) an Environmentally Dependent Application System (EDAS), based on sonic anemometer and GPS, allowing to automatically manage the air flow rate on the two sides of the sprayer and to manage spray quality. According to the wind conditions at the time of the application and according to the position of the sprayer within the orchard (e.g. boundaries) conventional or air induction nozzles are activated.

CIS is based on the use of ultrasonic sensors to detect real time presence and characteristics of the vegetation in front of the sprayer. On the basis of the acquired information, 6 pressure valves - one per each spray band - and 48 on/off valves - one per nozzle - are automatically driven in order to activate the nozzles and to adapt the amount of liquid sprayed and its vertical profile to the characteristics of the target (Fig. 3).

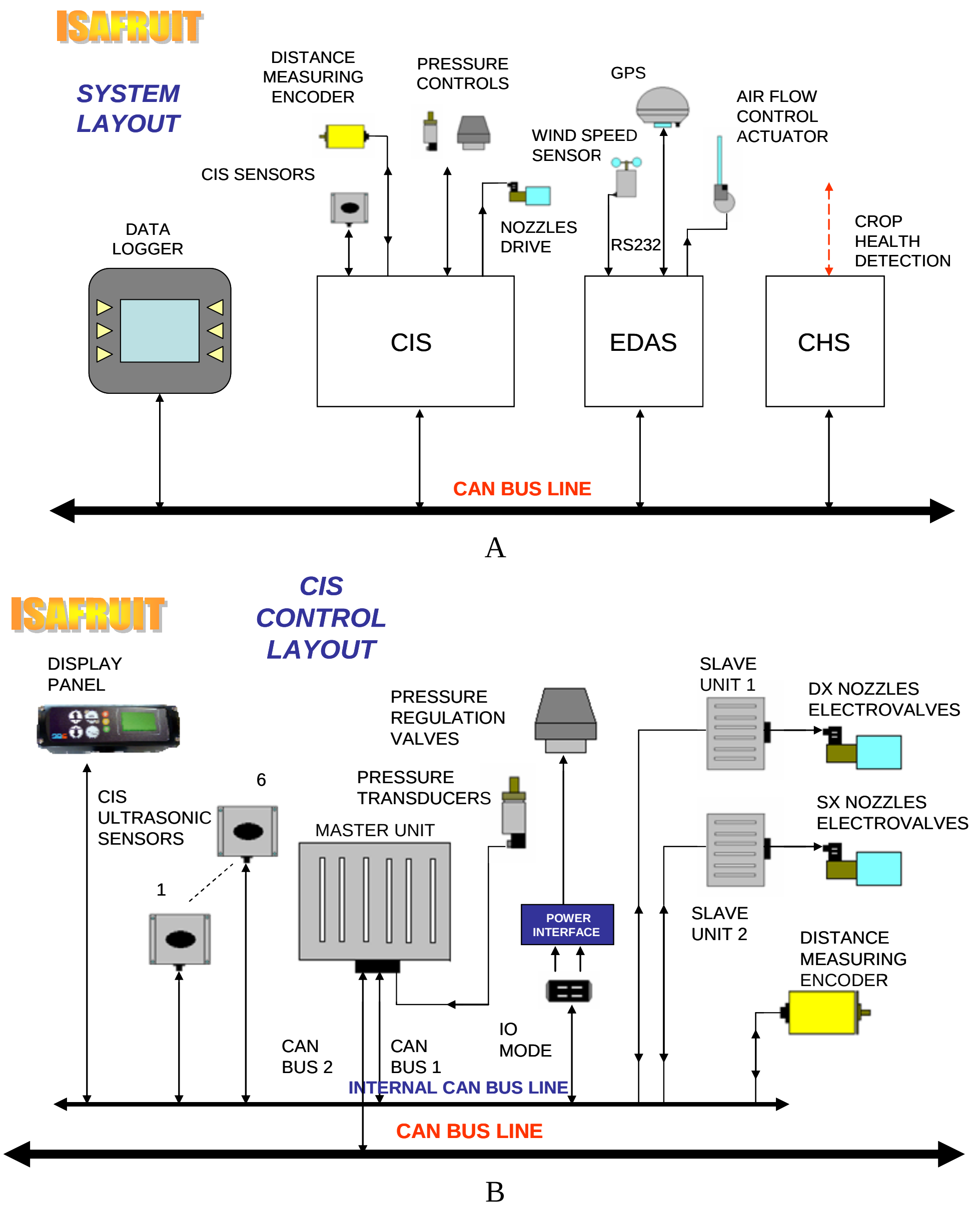

Figure 3. Schemes of the general system layout (A) and the Crop Identification System layout (B) used on the ISAFRUIT sprayer.

Six ultrasonic sensors, three per side, are displaced on a vertical support in the front part of the machine; each sensor is therefore responsible to detect the presence of the target and its characteristics corresponding to each spray band (Fig. 4).

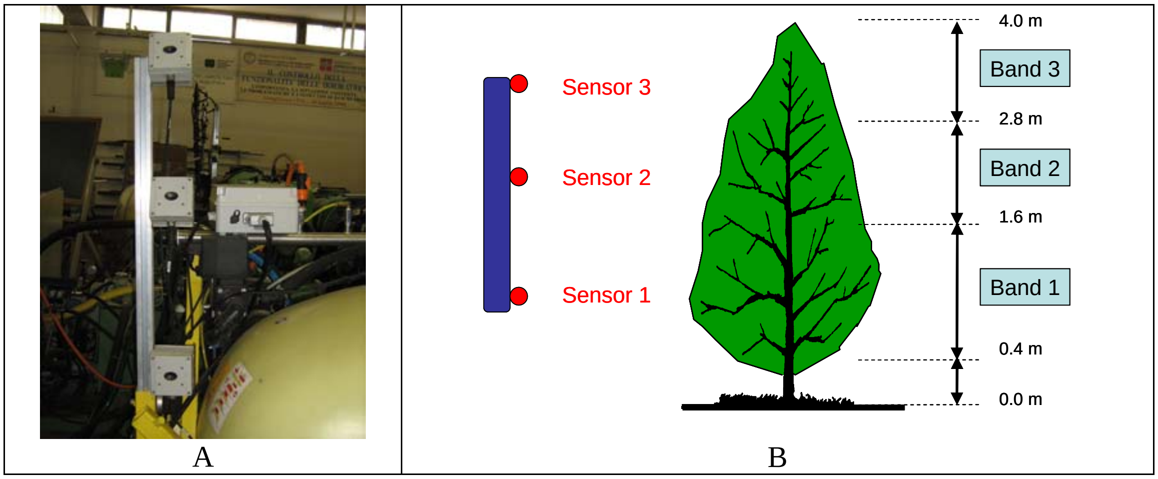

Figure 4. A) Ultrasonic sensors mounted on the sprayer prototype; B) scheme of the spray bands corresponding to the sensors positions.

The echo of the signal emitted by the sensor is then processed in order to obtain two sets of information: 1) presence of the target; 2) density of the vegetation.

The first information is relatively simple to achieve, as it depends on the time interval between the ultrasonic signal emission and the return of its echo; it is therefore possible to know the distance between the sprayer and the target and, combining this latter information with GPS data from EDAS, it is possible to estimate the thickness of the canopy facing the sensor. The assessment of the vegetation density is more complex, because it requires a deeper analysis of the ultrasonic echo signal: in fact, depending on the target density level, the analogical echo signal looks different: when the vegetation density is low (Fig. 5A), the signal oscillation is narrower with respect to the oscillation registered in presence of a high vegetation density (Fig. 5B). The elaboration of the echo signal then enables to get numeric thresholds than can correspond to levels of vegetation density.

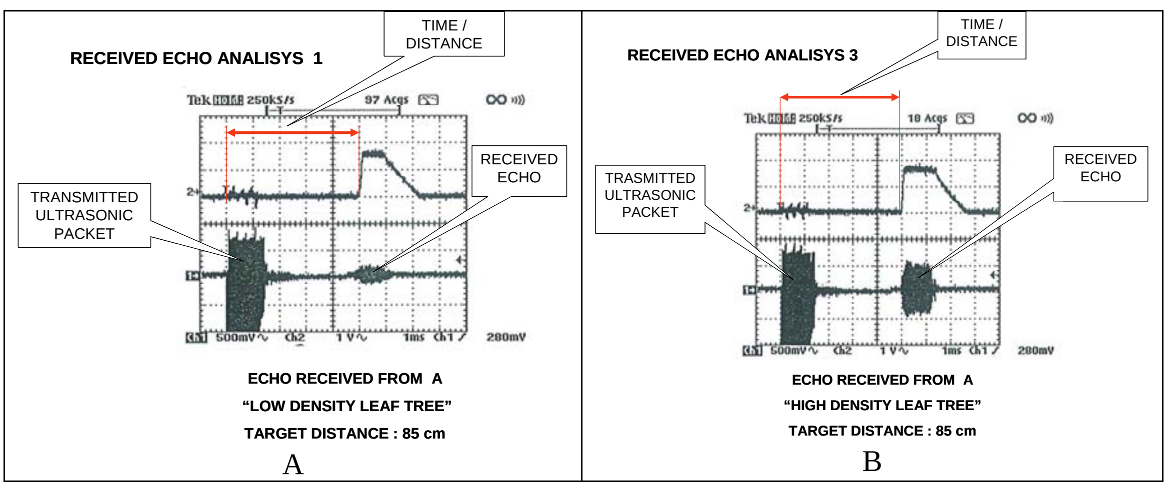

Figure 5. Examples of ultrasonic signals transmitted and received echoes from different canopy targets: A) low; B) high.

To verify the suitability of the sensors to detect the target, working in the range of forward speeds normally adopted for treatments in orchards and to check for eventual interferences between the three sensors mounted on the same sprayer side, several tests were carried out.

The first set of tests was conducted in an apple orchard (cv. Golden Delicious), situated in Verzuolo (Cuneo), North-Western Italy, featured by a layout of 4.5 m x 1.5 m and with maximum tree height of 4.0 m, using a single sensor positioned on a vertical support mounted on a trailed frame fitted with a wheel and an encoder to register the forward speed (Fig. 6). The sensor was placed at a height of 2.0 m from the ground and moved along the centre line of the inter-row: values of canopy thickness and density were acquired by the sensor every 10 cm of advancing, for a total test length of 70 m.

Figure 6. Device equipped with an ultrasonic sensor used in the tests.

Tests were aimed at: a) verifying the repeatability of results making three separate passes in front of the same row adopting a forward speed of 6 km h^{-1} and b) assessing the influence of different forward speeds (2, 4, 6, 8 km h^{-1}) on the vegetation profile acquired by the sensor.

Further tests in the same apple orchard rows, always working along 70 m length, were made operating at 6 km h^{-1} forward speed with three ultrasonic sensors positioned on the vertical support, therefore simulating their final displacement on the sprayer prototype (Fig. 3A): the sensors were mounted at different heights in order to address their signals towards three different bands of the canopy (0.4 - 1.6 m, 1.8 - 2.8 m and 2.8 - 4.0 m respectively). A comparison was then made between the results obtained for the central canopy band and those obtained using one single sensor.

3. RESULTS

Comparison of the profiles of the canopy thickness acquired for the same row in three different passes made at 6 km h^{-1} forward speed, showed fairly similar output, even if the point to point comparison often presented some discrepancies (Fig. 7), mainly due to the difficulty to repeat exactly the same path in the field with an accuracy of less than 10 cm.

Analysing the differences between the maximum and minimum values registered for each sampling point in the three test replications, it was observed that for about 80% of points discrepancies in thickness remained within 0.40 m (Fig. 8).

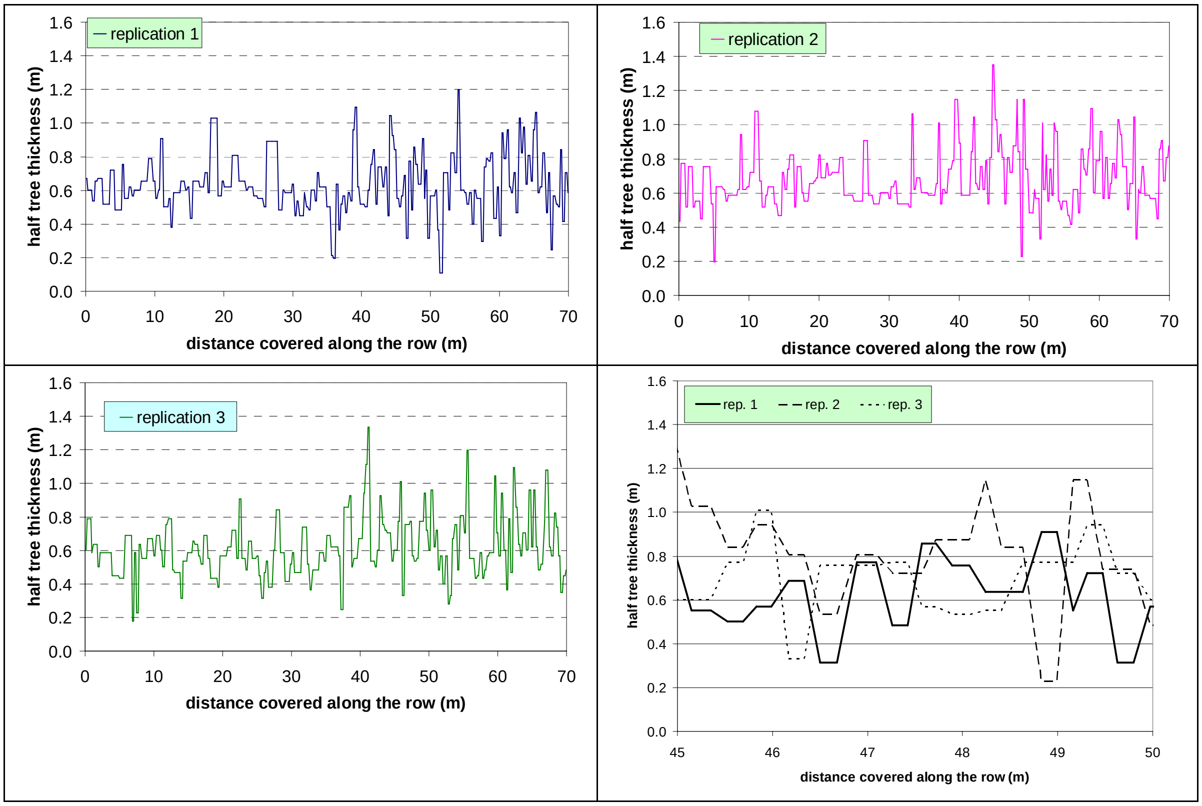

Figure 7. Profile of the canopy size detected by the ultrasonic sensor for the same orchard row working at 6 km h^{-1} forward speed in three different replications and detail of the three curves obtained along 5 m distance.

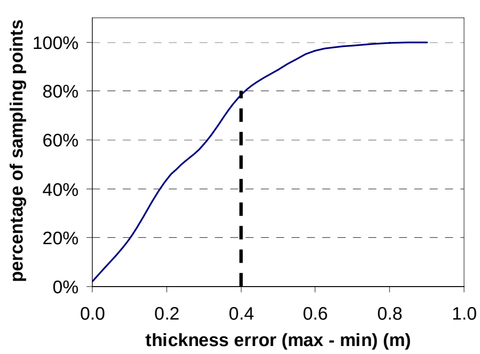

Figure 8. Canopy thickness discrepancies registered along the sampling points in the row, in the three test replications conducted.

Analogue results were obtained concerning the assessment of the vegetation density, that was expressed as index value (Fig. 9). Profiles of canopy density acquired in the three passes in front of the same row with the ultrasonic sensor resulted quite consistent.

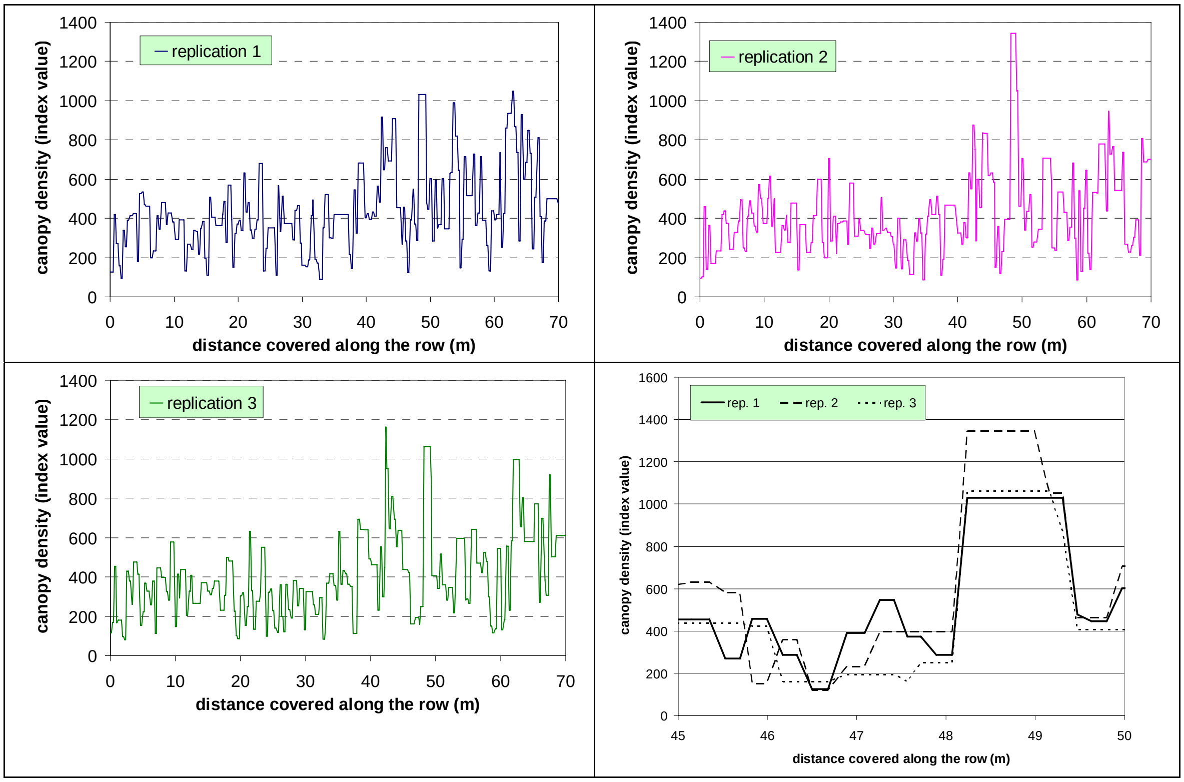

Figure 9. Profile of the canopy density (index value) detected by the ultrasonic sensor for the same orchard row working at 6 km h^{-1} forward speed in three different replications and detail of the three curves obtained along 5 m distance.

For about 80% of sampling points, discrepancies between maximum and minimum canopy density index values recorded in the three test replications ranged within 300 (Fig. 10).

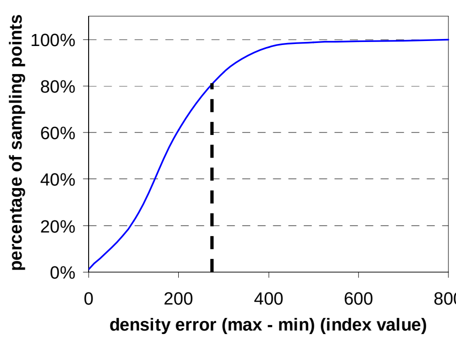

Figure 10. Canopy density discrepancies registered along the sampling points in the row, in the three test replications conducted.

Forward speed did not affect significantly the precision of the vegetation profile acquired by the sensor, either regarding canopy thickness (Fig. 11) or vegetation density (Fig. 12), as for each sampling position along the row, differences between maximum and minimum values obtained working at different forward speeds were not higher than those measured in the test replications made adopting the same forward speed (Fig. 13). For 80% of sampling points, in fact, canopy size discrepancies ranged within 0.25 m, while concerning the index values of vegetation density 80% of sampling points showed discrepancies within 250.

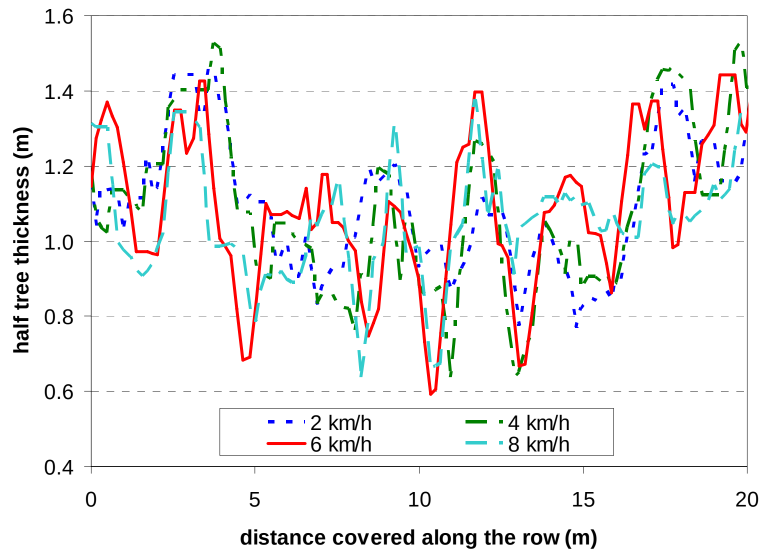

Figure 11. Profile of the canopy size detected by the ultrasonic sensor for the same portion (20 m length) of orchard row working at four different forward speeds (2, 4, 6 and 8 km h^{-1}).

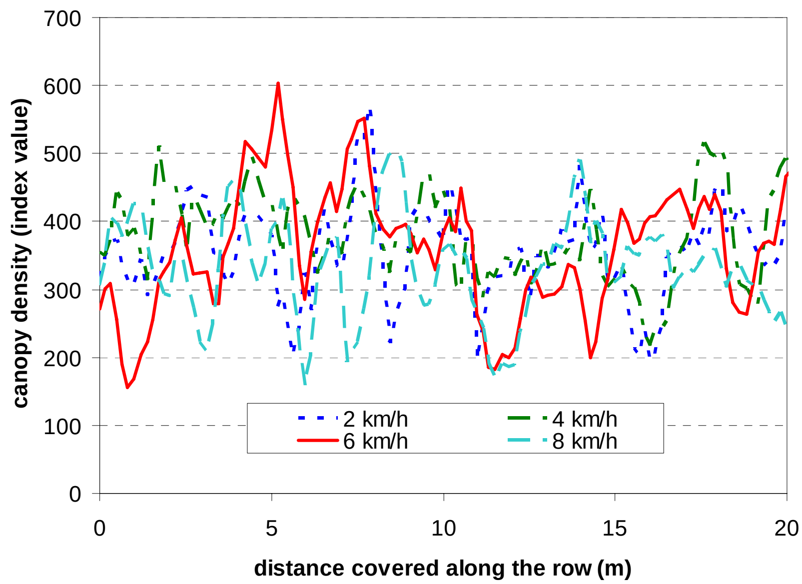

Figure 12. Profile of the canopy density detected by the ultrasonic sensor for the same portion (20 m length) of orchard row working at four different forward speeds (2, 4, 6 and 8 km h^{-1}).

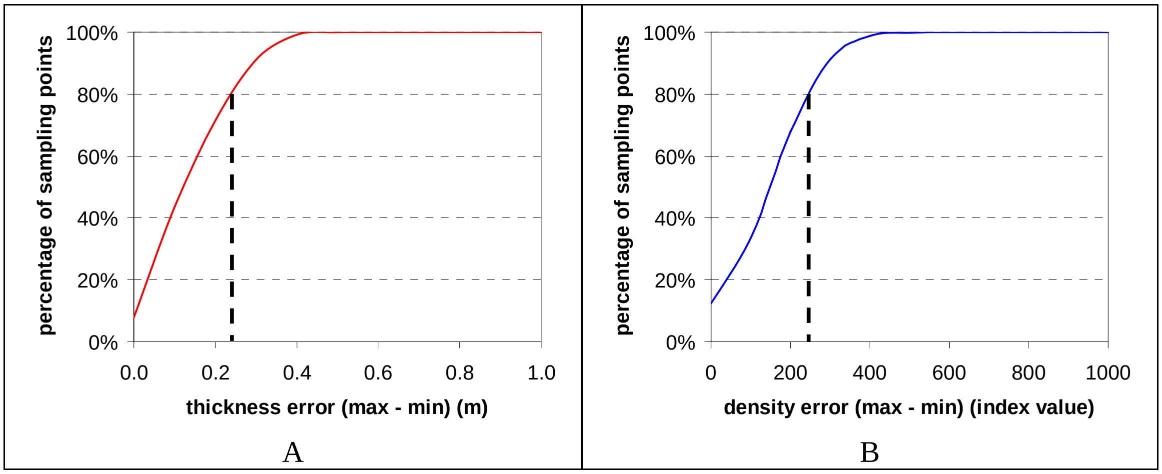

Figure 13. Discrepancies registered along the sampling points in the row comparing data acquired at different forward speeds: A) canopy size; B) canopy density.

Also the comparison between the results obtained regarding the central band of the plants (at about 2 m height) using the single sensor or the complete set of three sensor to equip one side of the sprayer, adopting always the forward speed of 6 km h^{-1}, showed no significant differences between the canopy profiles acquired (Fig. 14), proving that no interferences occurred between the sensors.

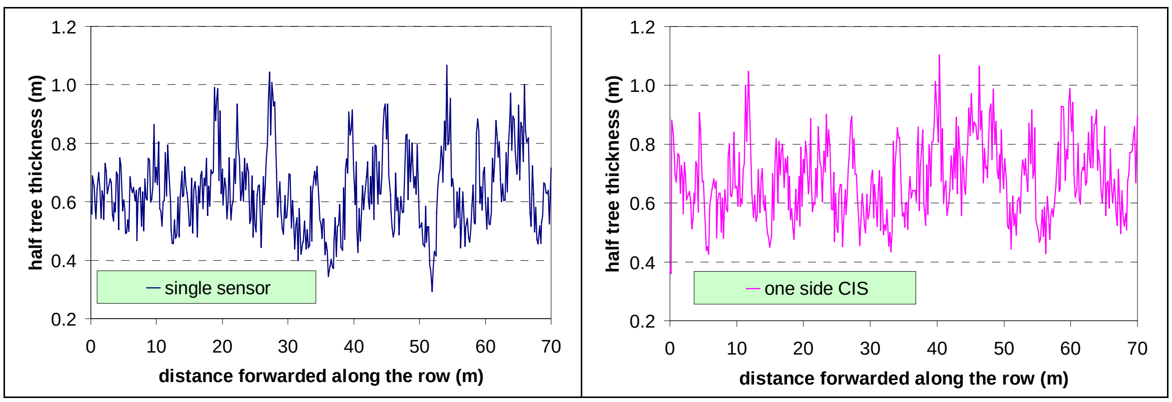

Figure 14. Profile of the canopy size detected for the same orchard row at about 2 m height working with one single sensor or with one complete CIS (three sensors per sprayer side).

4. DISCUSSION AND CONCLUSION

Test results pointed out that the CIS system developed is suitable to distinguish the presence and characteristics of the target to be sprayed and, as previous studies already indicated (Zaman and Salyani, 2004) is not significantly influenced by the forward speed adopted, working in the range (2 ÷ 8 km h^{-1}) commonly used during orchard treatments. No interferences were found between the three ultrasonic sensors that have to be mounted on the same sprayer side.

Nevertheless, it was evident that, in order to appropriately modulate the adjustment of the sprayer (number of active nozzles and operating pressure), it is necessary to consider an average of the last 10 measurements made by the sensors, corresponding to 1 meter of travel.

This value could be easily updated continuously, while the sprayer is travelling along the inter-row and would lead to have a continuous gentle adjustment of spraying parameters rather than a sudden regulation of them, depending on the target characteristics. Adopting this solution, moreover, discrepancies between the values recorded by sensors along the row resulted considerably mitigated (Fig. 15). As acquiring tests in the rows were conducted without any GPS assistance, it is to underline that at least part of the discrepancies found between test replications are due to the not exact overlapping of tractor paths between different passes in front of the same row.

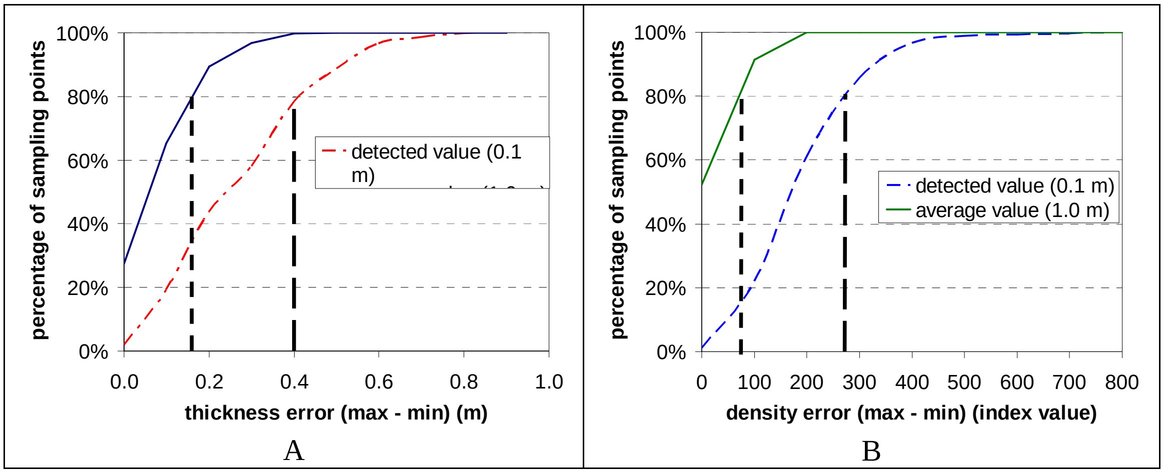

Figure 15. Discrepancies registered along the sampling points in the row - making three test replications at 6 km h^{-1} forward speed - comparing data acquired every 10 cm and average data calculated on the basis of 1 m advancing in the row: A) canopy size; B) canopy density.

Further developments of CIS and of the sprayer prototype are in course. On one hand, the work is focussed to build a sort of scale for the vegetation density, correlating thresholds of the index values to specific plants growth stages; on the other hand the functioning of the CIS equipped sprayer in the field is under study, in order to verify the robustness of CIS in operating conditions and to assess the benefits achievable with respect to the use of conventional sprayers that apply high volume rates.

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