Sensor Data Fusion for the Measurement of Horizontal Sprayer Boom Displacement

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Abstract

The measurement of horizontal sprayer boom movements is an important parameter for the simulation of repartition generated by a sprayer in the dynamic environment of agricultural fields. The existing methods were unsatisfactory for diverse reasons as limited measurement length or insufficient accuracy. Two different sensor data fusion methods were evaluated as input for a model aimed at predicting longitudinal spray deposit. A combination of radar and two accelerometers measurements was found more suited than laser and radar measurements combined in predicting spray repartition.

1. Introduction

Quality of agricultural practices are nowadays a major challenge for both environmental and economical reasons. Meanwhile pesticide spraying appears to be the most important factor among European intensive agricultural practices to reach high yields.

The treatment quality is directly related to the efficiency of spraying practices. Since the apparition of the first agricultural sprayer, many technological developments have been exploited to improve the performance of these machines. The global trend has led to ever larger sprayer booms. The main drawback is that these large structures are difficult to stabilise and the booms are consecutively submitted to high movements, directly responsible of deposit heterogeneity.

Mandatory tests for the assessment of sprayer boom dynamic behaviour are under development in various countries throughout the European Union. Whatever the methodology used, the objective aims at obtaining a global parameter of the spray quality resulting from standardised solicitations; the parameter most described and accepted for the repartition being the spray coverage Coefficient of Variation (CV).

For practical reasons and in order to avoid the numerous difficulties and limitations of repartition measurements, a repartition model of the repartition was developed [1]. The model consists in describing the nozzles trajectory as a probability density function in space. The model inputs are the nozzles trajectory (horizontal and vertical), the flow fluctuations and the static nozzle distribution, completed by the droplet population and the wind speed. The output consists in the spray dose for each space grid unit, what can be converted in spray coverage.

Two model parameters are linked to the sprayer dynamics: the vertical and horizontal nozzles displacement. While an accurate measurement of the first parameter can be easily obtained from several non-contact displacement sensors, the horizontal displacement measurements are of greater complexity and were the subject of extensive researches.

Various methodologies were developed; they can be divided into absolute and relative measurement methods:

- Relative displacement methods use the vehicle as referential; the sensor can be a laser distance meter [2] or a sprayer mounted camera.
- Absolute displacement methods are either based on accelerometers signal double integration [3] or on displacement transducers, as a laser distance meter [4], potentiometers [5] or a ground fixed camera [6], [7].

All the existing methods present some drawbacks for field condition measurements. In some cases, the method is tedious or restricted to small booms or to a small measurement length. In other cases, the measurement accuracy is limited due to the sensor inherent physical behaviour. In this paper, two methods are described that can provide continuous measurements of the boom horizontal absolute displacement. Based on the combination of information provided by several sensors, they are especially intended to predict spray deposit variations in relation to boom movements. They are specified for being used on agricultural fields, on a virtually unlimited length. Indeed, the random stochastic properties of agricultural fields as well as non-linear dynamic behaviour of sprayer mechanical structure creates the need for testing the booms in various experimental conditions.

Both methods were evaluated as an input for the repartition model. The obtained results were compared with the spray deposit measured in an especially designed experiment.

2. Sensor Data Fusion

2.1. Sensors

Two sensors' combinations were tested in order to get the most accurate measurement of the nozzle trajectory for repartition evaluation purpose.
The sensors used in this study are :

- A radar sensor mounted on the vehicle frame. This sensor provides an impulse output; the time between two successive pulses corresponding to a fixed distance. This sensor (45674 from Spraying Systems Co) is commonly used on agricultural vehicles for speed measurement.

- A laser distance meter mounted on the boom 6.25 m away from the centre. The laser beam was directed toward a tractor mounted target in such a way that distance measurement data are directly proportional to the relative horizontal displacement of the boom [2]. The sensor (DME-2000 from Sick Electronics) provides a 1 mm resolution for the distance measurement at 10 Hz in the 1-130 metre range.

- Two accelerometers mounted horizontally in the forward direction on the boom, respectively 6.25 m away from the centre (a1) and at the centre (a2). The CLX02LF3 (Crossbow) uses a micro-machined capacitive sensor with ± 20 m/s² span and DC-125 Hz bandwidth with typical 0 m/s² drift of 0.3 m/s².

2.2 Laser distance-meter and radar

The information measured from the two sensors were combined using a simple summation, assuming that the boom position at one time $X_l(t)$ results from the combination of the vehicle position $X_v(t)$ and boom displacement relatively to the vehicle $X_{l/v}(t)$.

$$X_l(t) = X_{l/v}(t) + X_v(t) \qquad (1)$$

This relation is exactly true only if the vehicle is not submitted to any acceleration. In practice, it can be valid if the resulting vehicle vibration are of small amplitude compared to the boom movements. The main difficulties encountered with this method come from the signal synchronisation from different sensors.

2.3 Accelerometers and Radar

Theoretically, the double integration of the accelerometer "a1" signal furnishes the absolute nozzle position.

$$X_1(t) = \int_0^t \int_0^t \ddot{x}_1(t) d^2 t \qquad (2)$$

When this treatment is applied to the accelerometer "a1", the cumulative summation of systematic errors appears in the low frequencies.

The analysis of the systematic errors shows that the main components result from the misalignment of the sensor relatively to the horizontal plane caused by pitch motion. A 0.1° misalignment for 10 second of time results in a 85 cm error in displacement. Drift (sensor dependent) is also present but in the lowest frequencies and is of smaller magnitude.

The presence of systematic errors in the integration procedure opens the way for a systematic correction of $X_{a1}(t)$. The errors caused by the slope component on the acceleration measurements were similar in the boom centre because the effect of the structure torsion is negligible, so $X_{a2}(t)$, the signal of the centred accelerometer, computed the same way as $X_{a1}(t)$ was subtracted.

$$X_{a/v}(t) = X_{a2}(t) - X_{a1}(t) \tag{3}$$

The resulting signal $X_{a/v}$ contains only the relative displacement between the vehicle and the boom plus the drift of the sensor. A part of the drift can be filtered removing the lowest signal frequencies. To recompose the absolute displacement, the signal must be combined with the vehicle displacement, the low frequencies being the same for the vehicle and the boom, which would otherwise mean an important structural damage.

$$X_{a}(t) = X_{a/v}(t) + X_{v}(t) \tag{4}$$

The choice of the optimal frequency cut-off was determined through the comparison of simulated and observed repartition.

3. Evaluation of data fusion performance

3.1 Introduction

An experimental set-up was designed in order to test simultaneously the response to a bump test of multiple sensors mounted on the sprayer and to measure the repartition under the sensor located 6.25 meter away from the boom centre. The trial was conducted at 2.5 m/s on a 40 meter long tarmac track with a tractor mounted 1000 L, 18 metres wide sprayer. A front wheel rolled on a 8 cm height bump. The deposit repartition caused by the obstacle was collected on a large scale (10.5 m long, 0.9 m wide) white paper sprayed with an aqueous solution of nigrosine 0.3%. The paper was scanned in 256 grey levels at 100 dpi with an A0 scanner and the repartition was calculated on the image using image analysis.

The two different sensor combinations were evaluated by the comparison between the measured longitudinal repartition (as reference) and the repartition computed using the repartition model, the only variable input parameter being the nozzle trajectory obtained from data fusion.

3.2 Laser distance-meter and radar

Figure 1 presents the longitudinal repartition obtained using the model (bold) and the measured repartition (thin). The correlation coefficient was 0.86.

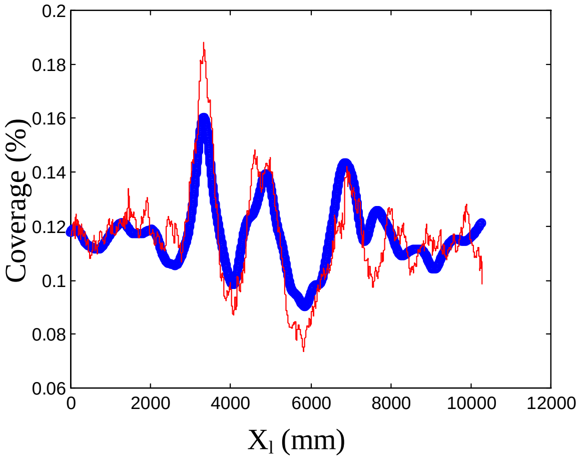

Figure 1: Percentage of measured and simulated coverage using laser and radar data.

3.3 Radar and two accelerometers

The optimal correlation was obtained from the accelerometer data $X_{a/v}$ filtered by removing from a Fast Fourier Transform the terms corresponding to a frequency lower than 0.15 Hz. Figure 2 presents the longitudinal repartition obtained using the model (bold) and the measured repartition (thin). The correlation coefficient was 0.92.

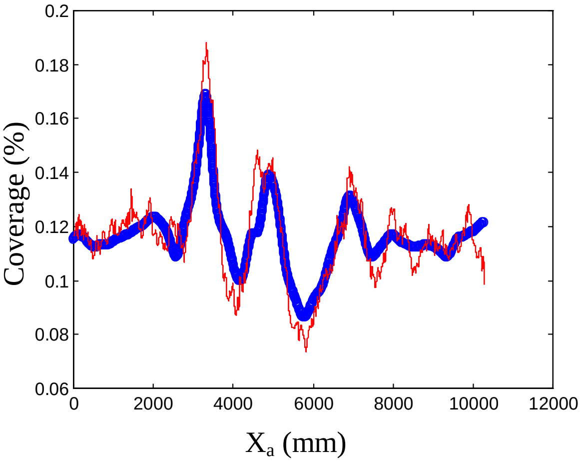

Figure 2: Percentage of measured and simulated coverage using accelerometers and radar data.

4. Discussion

The correlation coefficient may be considered as an indicator of the intrinsic quality of the information contained in the displacement data from different sensors' combinations. Indeed, the model was only fed with horizontal displacement data while many parameters (wind, height, flow, nozzle pattern…) involved in the simulation were kept constant and may need to be taken into account to further optimise the model. The results of the study show however that the longitudinal repartition is to a large extend linked to the horizontal boom movements. The accelerometers method provided the best results.

Acknowledgements

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