Obtaining yield maps in orchards by tracking machine behavior

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Abstract

In hand harvested citrus orchards fruits are usually stored in big bags or containers in the fields until they are picked by a crane and loaded into a truck. Yield maps for this type of harvest are mostly based on georeferencing the position of bags and later calculating yield at these points. A method of tracking the loading machine movement with low cost GPS receivers and post-processing data using filters is herein proposed to locate bag's position, and allow reliable yield mapping without the need of human interaction in the existing harvest procedure. Up to 86% accuracy on locating bags was obtained by tracking the difference in altitude of the crane's lifting arm while loading bags.

Introduction

The yield map is a widespread concept and possibly the most crucial information in a successful precision agriculture system. It is more frequent in mechanically harvested crops where sensors and yield monitors installed in the harvesters collect data. However mapping yield in hand-harvested crops is still a challenge either because of lack of methodology or because it demands procedures that interfere in the existing harvest process.

Among other perennial crops, the citrus crop is a prime example is this type of harvest and requires a suitable method for yield mapping. Although mechanical harvesters have already been developed, hand-harvest is still predominant in Brazil and United States, the two largest producers. Fruits are picked manually and placed into rigid containers (Florida, USA) or into "big bags" (São Paulo, Brazil). Afterwards, a crane is used to lift each bag and discharge it into a transportation vehicle while moving along the plant rows.

Techniques to map yield in this type of harvest have been developed and they are mostly based on georeferencing and calculating yield in each bag (or container) in the field (Tumbo et al., 2002; Molin et al., 2007). The harvested area needed to fill up each bag is estimated and then related to the bag volume capacity to generate yield values. The resulting data will furthermore be interpolated to generate the yield map. Despite its simplicity, this method demands human activity for collecting data which is a major limitation to adoption of this technique and a source of uncontrolled error - the coordinates of each bag must be collected on the ground by a GPS receiver, either by scouting every bag in a limited time frame (before the crane picks the bag), or by the crane operator at the time of lifting.

An automated and reliable data collection system that demands no human interaction for functioning would be a solution for yield mapping in this harvest system. This might be achieved by monitoring the crane performance while loading. Tracking machine movement patterns would allow bag's position recognition through post-processing

GPS data or even in real-time, without human interference or any disturbance in the actual harvest procedure. If a simple low cost GPS receiver could be used along with an algorithm for post-processing data for yield mapping, advances could be achieved in PA adoption by citrus growers as well as in other crops that use the same type of harvesting and loading procedure.
Thus the goal of this study was to propose algorithms for estimating the bag's position from georeferenced data of movement patterns of a loading machine, therefore providing information for yield map generation in orchards.

Methods

A model was proposed to identify the presence of bags and implemented in Microsoft Excel ™. Figure 1 outlines three different filtering methods for estimating the presence of a bag in accordance with the machine's behavior. The methods herein tested require two GPS receivers, set to record data at a certain time frequency, which are attached to different parts of the on-field crane. One GPS is attached at the base of the crane and the other is attached to the edge of the lifting arm.

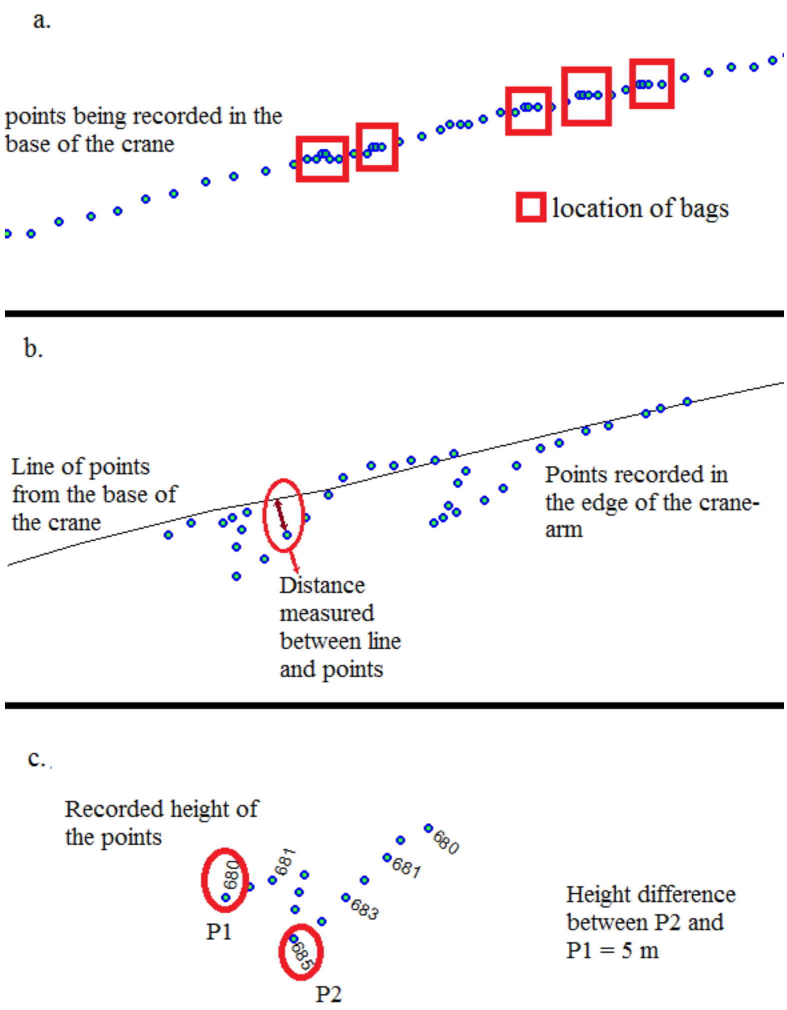

Figure 1. Methods used to identify the presence of the bags.

The three filtering methods shown in Figure 1 are:

a. *Determining the presence of bag by the stops of the machine.*

Using only the GPS fixed in the base of the crane, Figure 1 (a) shows how the recorded points are distributed during the movement of the machine. The red squares indicate the position where the machine stops to pick one bag from the ground and lift it to the carrier, where an accumulation of points occur. The method used for estimating the presence of bags is based in detecting this accumulation. The model for this method uses two parameters:

- A maximum distance between points (MDP) that defines a group of points belonging to the same location;
- The minimum number of points (MNP) that must be located inside that range to infer the existence of a bag;

From the set of records from the GPS, the model goes along them grouping the points in the user-given MDP and counting these, when count matches or surpasses the MNP, a bag exists at that location.

b. *Determining the presence of a bag by the lateral swing of the crane's lifting arm into the carrier*

While one GPS is storing data from the base of the crane, which is illustrated by the black line in Figure 1 (b), the other GPS records data from the edge of the lifting arm. The points recorded by this are shown moving away and back to the line. Points away from the line represent the movement of offloading a bag on a carrier. The model for this method uses one parameter: minimum distance of the point of the arm from the line (MDA). The model runs along the points recorded and identifies when the distance between the point and the line exceeds the MDF defining that a bag is about to be unloaded. Once a point reaches this level, the subsequent nearby points are blocked from determining the unloading action again at the same place.

c. *Determining the presence of a bag by the difference of height of the crane lifting arm*

The GPS on the edge of the lifting arm also stores its elevation, and the elevation recorded when a bag is being attached on the ground differs from the elevation when it raises a bag upon the carrier. The difference in elevation, illustrated in the point labels in Figure 1 (c), can determine the presence of a bag. The model, in this case, requires two parameters:

- The position of a point prior to the point of maximum elevation (respectively points P1 and P2, where the first is positioned 6 points behind the latter);
- The minimum height difference (MHD) required to infer the lifting of a bag.

The model runs along the points subtracting the height of P1 from P2 (located some points ahead) and identifying when the MHD is reached. Once the difference is found, the approaching points are blocked from marking a new bag (in case the difference suggest so) to avoid determining more bags being lifted at the same place.

Example case study

A citrus loading machine with a telescopic and articulated hydraulic lifting arm was evaluated while loading 68 bags from a 4-year old commercial orchard in the São Paulo state, Brazil. During the harvest, the bags were aligned in the center of four harvested tree rows (7 m of rows spacing). Before loading, the coordinates of bags were collected using a GPS receiver as a ground truth measurement of bags' positions. The loading machine moved along the inter-row where the bags were placed and carried each one over the tree canopy to discharge it into a loading truck that ran along the adjacent inter-row space (Figure 2).

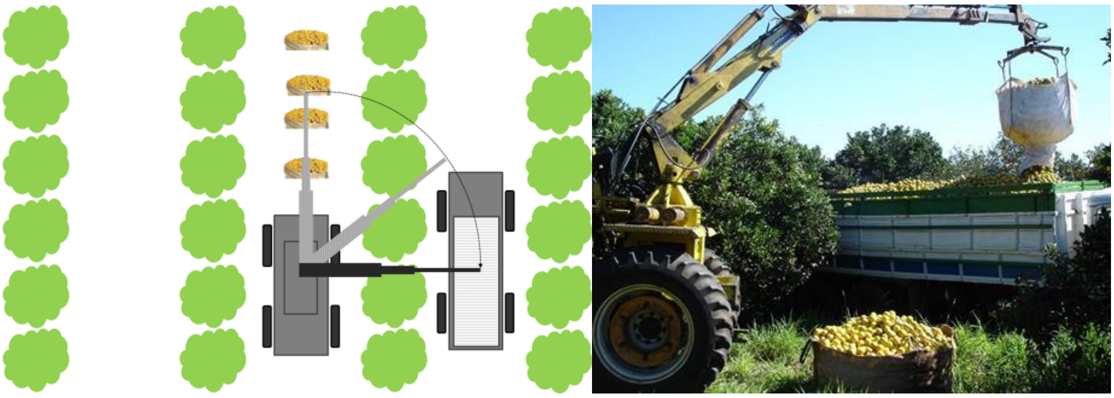

Figure 2: Crane used to pick bags of oranges and load it onto a truck running in the adjacent inter-row space.

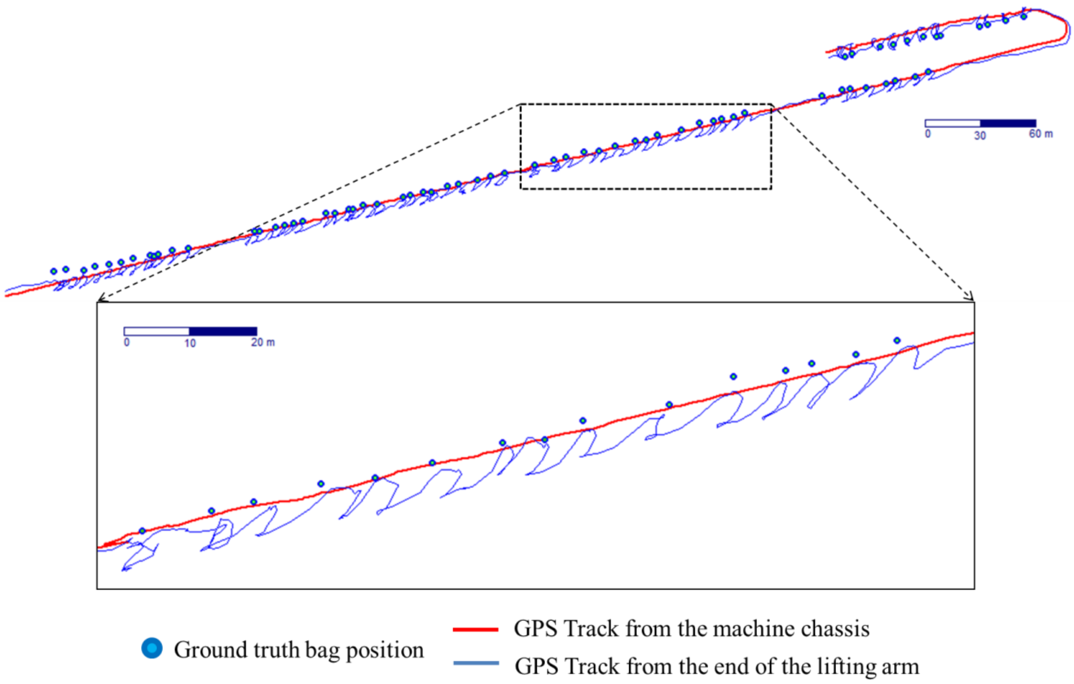

Figure 3: Raw data from the two GPS receivers used to track machine movements and the ground truth bag position measured by a third GPS receiver.

Two GPS receivers were attached to the loading machine: one on its chassis (0.7 m from above the ground) (eTrex Legend® H, Garmin) and the other, with built-in barometric altimeter, on the edge of the lifting arm (GPSMAP® 62s, Garmin); both were set for storing their position at a frequency of 1 Hz (Figure 3). The first receiver collected data to retrieve the condition of the machine (still or moving, filter a), while the other registered the behavior of the lifting device, storing its transversal, longitudinal and vertical movements (filter b and c). Each record from the GPS receivers contained the information of time, coordinates and the altitude (registered by a built-in barometer).
Sensitivity analyses were carried out on the parameters used in each filter to find the best configuration for locating bags.
The estimated points were compared with the ground truth measurements to determine if each point referred to an existing bag or if the model missed a bag or if it marked an absent bag. The probability of success of finding bag's location was calculated using equation 1.

$$P = \frac{RE}{RE+BU+AB} \times 100 \qquad (1)$$

Where,

P, probability of success of finding bag's location (%);
RE, number of right estimations;
BU, number of bags unmarked;
AB, number of estimated points on absent bags.

Results and Discussion

Table 1 shows the results of a sensitivity analysis applied to the two parameters used to locate bag position in the first model (the minimum number of points – MNP –and the maximum distance between them – MDP – to characterize one stop), as well as the total number of bags estimated in each combination. Some combinations of MNP and MDP estimated a total number of bags close to the real number of bags (68 in total) recorded by the ground truth georeferencing. The model was then configured to use 15 points and a maximum distance of 2 m between them to define the presence of one bag.

Table 1.Sensitivity analysis for the two variables in filter (a) and the number of estimated bags.

MDP (m)	MNP 5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	number of estimated bags															
0.5	110	99	90	84	74	66	64	57	49	43	34	27	22	19	15	12
1.0	95	93	91	88	85	83	74	71	65	56	47	40	33	23	17	15
1.5	94	92	88	87	87	85	80	75	72	67	57	52	38	32	24	19
2.0	96	89	88	87	87	85	83	79	76	73	69*	62	55	45	36	30
2.5	98	90	88	87	85	84	82	80	78	76	75	69	60	49	44	35
3.0	103	96	92	92	91	91	90	89	87	82	80	76	71	60	49	43

< 68 = 68 > 68
* Results plotted in Figure 5.

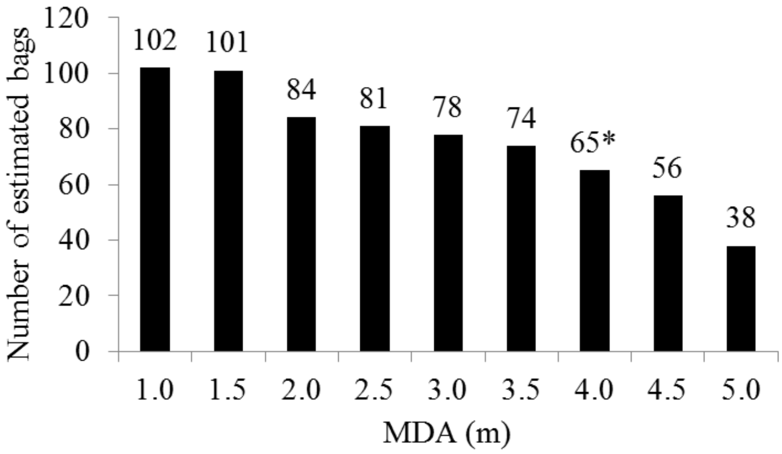

Figure 4. Sensitivity analysis in filter (b) varying the minimum distance of the lifting arm (MDA) to the crane's line track and the total number of bags estimation.
* Results plotted in Figure 5.

A sensitivity analysis was also carried out on filter (b), varying the minimum distance of the lifting arm (MDA) to the crane's line track (Figure 4). As the distance increased, fewer points are marked as bags. The best result was found using 4 m of MDA to retrieve bag positions. That was the configuration used in this filter to proceed with the analyses.
In the third filter (c), varying its two parameters (MHD and PP) yielded good results on several combinations (Table 2). Looking at three points behind the point of maximum elevation to find height differences of at least 3 m was used to configure this filter.

Table 2. Sensitivity analysis for the two variables in filter (c) and the number of estimated bags.

MHD	Position of a point prior to the point of maximum elevation (PP)														
(m)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	--------------------------- number of estimated bag ---------------------------														
0.5	169	195	195	195	195	195	195	195	195	195	195	195	195	195	195
1.0	80	157	192	195	195	195	195	195	195	195	195	195	195	195	195
1.5	28	120	151	195	195	195	195	195	195	195	195	195	195	195	195
2.0	1	76	139	154	195	195	195	195	195	195	195	195	195	195	195
2.5	0	51	100	140	166	195	195	195	195	195	195	195	195	195	178
3.0	0	15	73 *	119	146	173	195	195	195	195	195	195	195	180	160
3.5	0	1	44	81	128	146	166	177	191	195	195	195	177	157	136
4.0	0	0	11	50	79	107	129	145	156	165	174	160	157	135	119
4.5	0	0	1	17	41	58	72	86	96	114	120	121	119	108	96
5.0	0	0	0	0	6	15	15	28	31	44	50	64	70	66	55

< 68 = 68 > 68
* Results plotted in Figure 5.

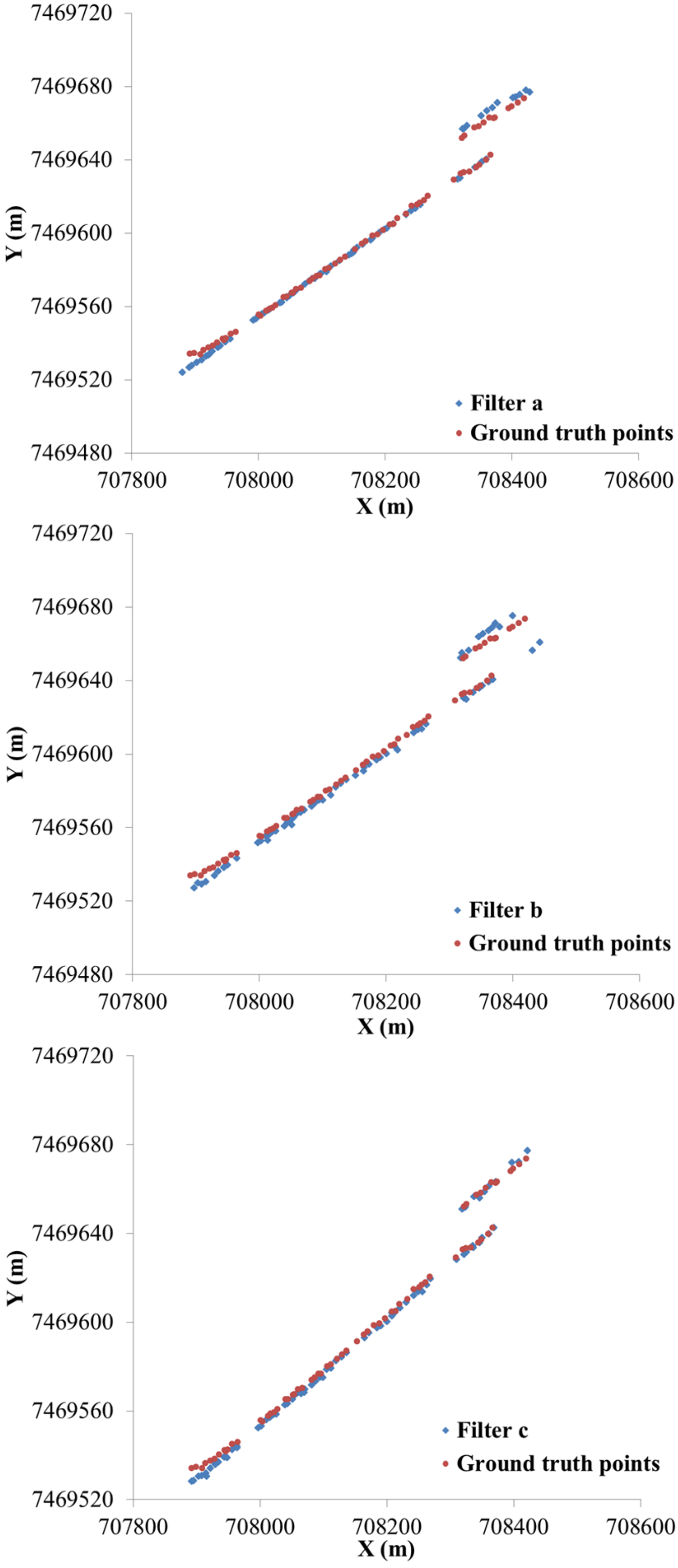

Figure 5. Estimated bags' locations by each filter from the machine movement data.

Filter (a) got 78% accuracy on finding bags' positions, (Table 3). One limitation of this filter method was the fact that the machine had to stop for both lifting and then discharging the bag into the loading truck. Both stops needed similar duration making it difficult to distinguish them.

The filter based on the transversal movement of the lifting arm (filter b) got 77% probability of success on finding bags' locations. This method is only suitable when the loading truck runs along an adjacent tree row to the loading machine itself, which demands it to perform an over-the-tree movement of the lifting arm. In mature orchards the larger trees might prevent the lifting arm to cross over the canopies, so the truck needs to run along the same row-space as the loading machine. The best result was found using the altitude data from the lifting arm (filter c). This method got 86% probability of success on finding bags' positions.

Table 3. Descriptive performance of filters

Filter	Ground truth records	Total estimated points	Right estimation	Missing a bag	Marking an absent bag	Probability of success (%)
a	68	69	60	8	9	78
b	68	65	65	11	6	77
c	68	73	65	3	8	86

Further work will look at replacing the lateral filtering by one that checks changes in direction of the lifting arm. Also testing more accurate GPS receivers and higher frequency of data collection could enhance accuracy on the estimation of bags position. Combining filters may also reduce the risk of marking an absent bag.

Conclusions

In manual citrus harvesting bags may be located by post-processing data collected from the loading vehicle movements and thus provide information for yield mapping. The method would require no human interaction for data collection.

So far, good results were obtained in a first trial when using a simple low cost GPS receiver for data collection. The filter that used the altitude data from the crane's lifting arm gave the best results in finding bag positions.

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