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Development and Experiment of a Smart Scale to Improve Packaging of Flower Cuttings

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The actual quantity of product units in prepacked packages is an issue that concerns both the consumer and the producer. The consumer has the right to expect packages to bear accurate net content information, and the producer aims to pack the specified nominal quantities at minimum cost. Accurate weight-based packing of 'packages labelled by count' necessitate very low 'coefficients of variation (CVs) of unit weight. For agricultural products, with relatively high CVs, the usual weighing methods are therefore not suitable. The present study suggests a methodology that supports the count-to-weight transform of prepacked packages of products with wide variability of characteristics. We developed innovative weighing algorithms to produce 'packages labelled by count' and a prototype of a smart scale. The prototype consists of a digital scale; a controller; and, a visual and sound interface. The algorithms were embedded into the controller to facilitate accurate number of counts in a package. The prototype is able to work in two states: 1) calibration – to calculate the critical weight according to the cultivar and package type; and, 2) weighing – loading cuttings on the scale until the critical weight is reached. An experiment to examine the two states was conducted and the results indicate that in the calibration state, the calibration time increased linearly with the package size. In the weighing state, the average packing time per cutting unit was reduced from 1.2 s per unit for a 10-unit package to 0.2 s per unit for a 50 unit's package. The actual number of units in a package was higher than the nominal number but the variability between the different packages was low indicating that the algorithm, the methodology and the prototype succeeded to decrease the variability but need to be calibrated and refined so that the number of actual units per package will be similar to the nominal number.

1. Introduction

The actual quantity of product units in prepacked packages is an issue that concerns both the consumer and the producer. The consumer has the right to expect packages to bear accurate net content information, and the producer aims to pack the specified nominal quantities at minimum cost. Routine verification of the net contents of packages is an important part of any weights and measures program intended to facilitate value comparison and fair competition.

There are several methods to quantify the contents of prepacked packages: counting, weighing, or volume measurement. The goal of every manufacturer is to pack the specified nominal quantities into a package, at minimum cost. In various industries (food, agriculture, plastics, machined products, wood, pharmaceuticals, etc.) there is a need to create packages with a nominal content defined by a specified numerical quantity. Some products, e.g., screws, may be packed by automatic means, mainly due to very small weight variability. Others, unfortunately, must be packed manually, because their wide variability of characteristics which prevents any economic justification for an automated solution, or because there is no feasible automated solution. When the quantities involved in each package are large, two problematic issues need to be addressed. i) The manufacturer tends to design a packaging strategy ensuring that the nominal quantity is achieved. This is usually done by adding a fixed percentage, e.g., 10%, of the nominal quantity to each package. ii) There is a problem with the employee performing the counting task. This is a very monotonous and tedious job, which encourages the employee to apply large personal safety margins. The outcome of both these issues is packages that contain more than the nominal quantity (overfilling).

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The present study suggests a methodology that supports the count-to-weight transform of prepacked packages of products with wide variability of characteristics. Different products have differing CV values (Mizrach et al., 2003). In packaging of plant cuttings Vitner et al. (2006) found that the CV ranged from 0.17 to 0.23. (Hetzroni et al., 2001) investigated injuries to apples during harvest and transportation, and found that the CV was 0.17. Zion and Lev (1996) investigated a weighing method as an alternative procedure for sorting, Aster, Hipericum, Solidaster and Solidago cuttings, and reported that their CV is ranging from 0.22 to 0.54, and Cronin et al. (2003), who investigated the weight variability in extruded food products, found the CV ranged from 0.047 to 0.096. Hauhouot-O'Hara et al. (2000) calculated the CV of the length, width and thickness of seeds in the process of selecting the size and shape of holes in screens used to separate chaff from wheat; Morales-Sillero et al. (2008) used CV as an aid in verifying the influence of nutrient supply on olive dimensions (weight, length and equatorial diameter); Hoffmann et al. (2007) used CV measurement to determine the distribution of foreign material inside the box during potato harvesting.
The objective is to develop an innovative weighing algorithm to produce 'packages labelled by count' and a prototype of a smart scale. An experiment to validate the model prototype was conducted.

2. Methods and materials

2.1 Count-to-Weight Transform Methodology

In order to utilize the transform methodology we assume that the package weight, w is distributed normally (i.e., the package weights are normally distributed, under the assumption that the number of individual items in each pack is large, usually above 30) based on the Central Limit Theorem.

$$\mathrm{w} = \mathrm{N} \sim \left(\mathrm{n} \cdot \mu, \sqrt{\mathrm{n}} \cdot \sigma\right) \tag{1}$$

Where μ is the average weight of one product unit, σ is the standard deviation of the weight of one product unit, w is the distribution of package weights, and n is the nominal number of product units in a package.
Five basic packaging characteristics were defined: $\bar{\mathrm{n}}$ – the mean number of items in a package; n_L – the minimum number of items in a package; n_U – the maximum number of items in a package; Δn – the range of numbers of items in a package, where $\Delta\mathrm{n} = \mathrm{n}_{\mathrm{U}} - \mathrm{n}_{\mathrm{L}}$; and, CRn – the ratio between Δn and $\bar{\mathrm{n}}$ (Bechar and Vitner, 2009).
The aim of any farmer is to deliver to the market packages that comply with the specified nominal number of units, and they may adopt various strategies, depending on market or customer demands, such as the minimum quantity package strategy in which the number of units in a package (n_L) should not be less than n – δ. The basic characteristics of the package can be calculated according to the product CV and the farmer's strategy.
The critical package weight is the minimum allowable weight of a package; it is calculated according to the basic characteristics of the package and the average weight and standard deviation of the product, enabling the worker to decide whether a package complies with the requirements.
In a given population of packages with mean weight Wμ, the maximum and minimum number of items in a package, n_U and n_L, respectively, and the range of numbers of items in a package can be expressed in terms of the coefficient of variation, CV, and the nominal number of items in a package, n:

$$W_\mu = n \cdot \mu = n_L \cdot \mu + 3\sqrt{n_L} \cdot \sigma = n_U \cdot \mu - 3\sqrt{n_U} \cdot \sigma \tag{2}$$

$$n_U = \frac{9}{2}CV^2 + n + 3CV \cdot \sqrt{\frac{9}{4}CV^2 + n} \tag{3}$$

$$n_L = \frac{9}{2}CV^2 + n - 3CV \cdot \sqrt{\frac{9}{4}CV^2 + n} \tag{4}$$

$$\Delta n = 6CV \cdot \sqrt{\frac{9}{4}CV^2 + n} \tag{5}$$

Where: $CV = \frac{\sigma}{\mu}$ (6)

For example, in the case of Petunia, the mean weight, μ, of a single plant cutting is μ = 0.297 g and the standard deviation is σ = 0.08 g. The mean weight of a package, Wμ, with nominal number of 100 plant cuttings is 29.7 g. The number of cuttings in such a package will range between 93 (n_L) and 109 (n_U). The number of items per package is rounded to upper nearest integer. If the requirements are that the number of cuttings in a package will not be below 100, then the average package weight will be 32.1 g. The mean number of cuttings, $\bar{n}$ in a package will be $\bar{n}$ = 108.1 and the maximum number of cuttings in a package will be n_U = 116.8 cuttings. A detailed analysis of the development was presented by Bechar and Vitner (2009).

2.2 Farmer packaging strategies

Packaging is a basic, but major postharvest task. The present study deals with packing a given number of units in a package for marketing. Counting is a very tedious task and usually farmers adopt a strategy of adding a percentage, e.g., 10%, to the nominal number to make sure that the package contents are as specified. This strategy results in additional costs with no additional revenue. The aim of any farmer is to deliver to the market packages that comply with the specified nominal number of units, and they may adopt various strategies, depending on market or customer demands. The following are the basic strategies.

A. Average – the average number of units in a package ($\bar{n}$) should be equal to a given number of units (n + δ), where n is the nominal number of units in a package and $\infty > \delta > -n+1$.
B. Minimum – the number of units in a package (n_L) should not be less than n - δ.
C. Maximum – the number of units in a package (n_U) should not be more than n + δ.
D. Range – the difference in the number of units between any two packages (Δn) should not exceed a given range;
E. Minimum plus a range – superposition of strategies B and D.

Table 1 presents the mapping of packing strategies and the relevant package characteristics.

For any packaging strategy, the CV of a unit of crop is given in addition to at least one of the packaging characteristics (e.g., for strategy B, the package characteristic n_L). This procedure enables the farmer to verify the threshold of the package weight and to derive the values of all other package characteristics.

2.3 Prototype Development

A prototype of smart scaling system based on the developed algorithm and methodology was developed (Figure 1). The system consists of: i) a digital scale with accuracy of 0.01 g; ii) a controller with the scaling algorithm; and, iii) a visual and sound interface. The system operates in two modes: a) calibration mode – to find the critical weight based on the model and package characteristics; and b) weighing mode – the flower cuttings are loaded on the scale until it reaches the critical weight. The visual – sound interface marks when the weight reaches 90% of the critical weight and at the critical weight.

Figure 1: The smart scaling system prototype.

2.4 Experiment

An experiment was conducted to examine the methodology and the model on the developed prototype. The experiment includes the calibration and weighing stages. In the calibration stage, packages of 10, 25, and 50 flower cuttings were examined. In the scaling stage, packages of 10, 25, and 50 flower cuttings were prepared with five repetitions each. In the calibration stage, the required time to determine the critical weight for each package size was measured and in the weighting stage, the required time to fill a package and the actual number of flower cuttings that were packed was recorded.

3. Results

The results indicated that the calibration time increased linearly with package size (Figure 2).

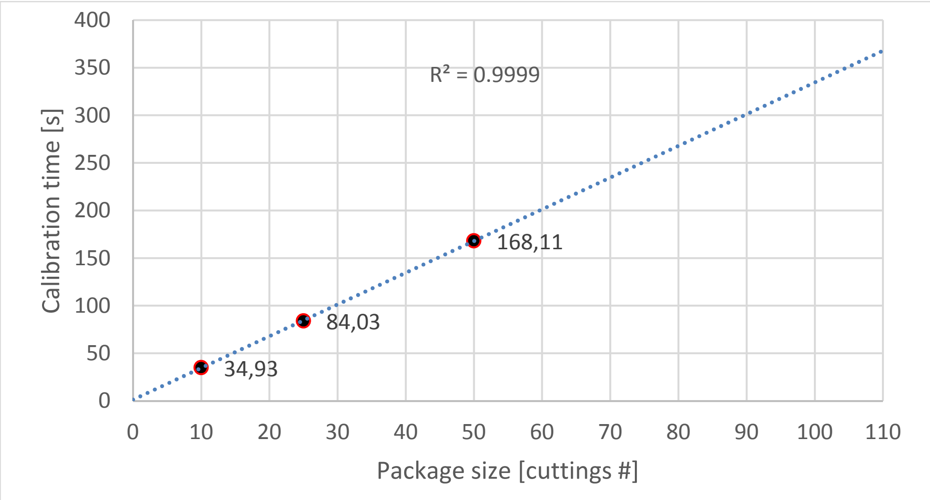

Figure 2: Calibration time vs. the package size.

The time is influenced mainly by the long cycle time of the current prototype, which stands for 3.5 s per a single weight measurement. In the weighing stage, the package filling times were 12.7, 17.8 and 10.3 s on average for filling packages of 10, 25 and 50 flower cuttings respectively. The average packaging time (filling) per one flower cutting decreased from 1.2 s in a 10 cuttings package to 0.2 s in a 50 cuttings package (Figure 3).

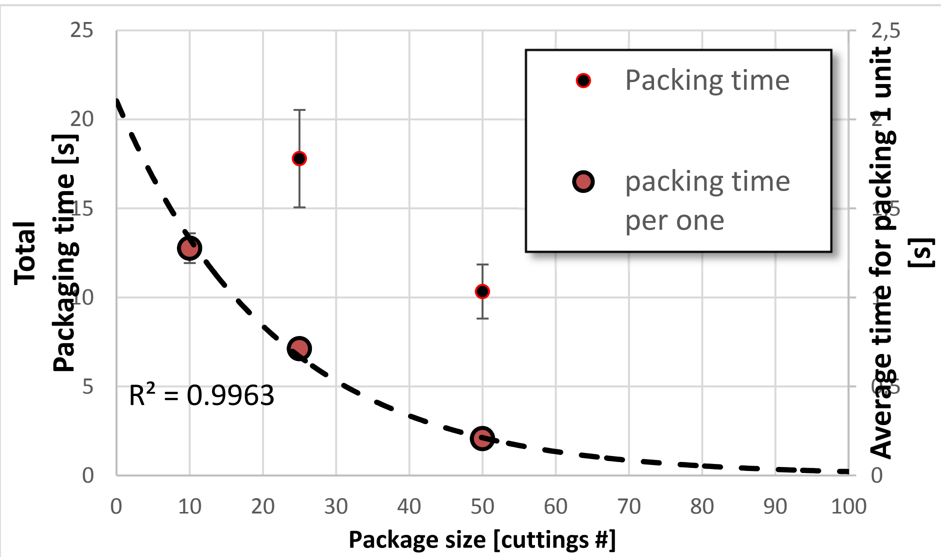

Figure 3: Package size distribution of a) current and b) modified methods.

The results of the weighing stage experiment are presented in Table 1.

Table 1: Actual and nominal number of flower cuttings in a package of the weighing stage.

Package size / nominal number [# cuttings]	n	Average number of cuttings	Minimum number of cuttings	Maximum number of cuttings
10	5	14.8	14	16
25	5	35	32	39
50	5	59.4	58	61

The actual number of flower cuttings in a package was higher than the nominal one but the range of the number of cuttings in the packages was lower. E.g., in a 50-cutting package, the actual number of packed cuttings was on average 59.4 cuttings per package, but the range for a single package was between 58 to 61. Which shows that the weighing algorithm, the methodology and the prototype reduced the variability between the packages. However, a calibration procedure needs to be developed to reduce the number of actual flower cuttings in a package to the nominal value.

4. Conclusions

The actual quantity of product units in prepacked packages is an issue that concerns both the consumer and the producer. The consumer has the right to expect packages to bear accurate net content information, and the producer aims to pack the specified nominal quantities at minimum cost.

Current accurate weight-based packing of 'packages labelled by count' necessitate very low 'coefficients of variation (CVs) of unit weight. For agricultural products, with relatively high CVs, the usual weighing methods are therefore not suitable.

The significance of this research are three folded: i) we developed a unique methodology that supports the count-to-weight transform of prepacked packages of products with wide variability of characteristics; ii) We developed an innovative weighing algorithm to produce 'packages labelled by count'; and, iii) Developed and constracted a prototype of a smart scale. The prototype consists of a digital scale; a controller, and, a visual and sound interface. The developed algorithms were embedded into the controller to facilitate accurate number of counts in a package. The prototype is able to work in two states: 1) calibration – to calculate the critical weight for the cultivar and package size; and, 2) weighing – loading cuttings on the scale until the critical weight is reached.

An experiment to examine the two states was conducted and the results indicate that in the calibration state, the calibration time increased linearly with the package size. In the weighing state, the average packing time per cutting unit was reduced from 1.2 s per unit for a 10-unit package to 0.2 s per unit for a 50 unit's package. The actual number of units in a package was higher than the nominal number but the variability between the different packages was low indicating that the algorithm, the methodology and the prototype succeeded to decrease the variability but need to be calibrated and refined so that the number of actual units per package will be similar to the nominal number.

The developed methodology made this packaging process to be more structured and industrial with fewer errors during the filling stage. The production rate was increase, the variability between packages from the same size and the time to fill and pack a package was reduced.

Future research is required on several aspects of this study: 1) the calibration and weighing times should be reduced. The main limiting factor was the time required for the scale to be stabilized on the weight of a single cutting in the calibration stage and on a batch of cuttings in the weighing stage; 2) a calibration procedure should be developed to reduce the number of cutting in a package to the nominal one or to investigate the causes for the different between the actual and nominal values; and 3) this methodology should be modified and tested on different packaging standards and strategies such as the NIST 133 handbook requirements (Vitner and Bechar, 2011).

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