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Impact Measurement on Apple and Orange Packinghouses Using a Wireless Instrumented Sphere

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Physical damage can be considered one of the main causes of postharvest losses for fruits and vegetables. One of the challenges is to measure the impact magnitude on packing lines. There is a number of equipment that can be applied, and the most common are instrumented spheres. A Wireless Instrumented Sphere (WIS) was developed being a low cost alternative that acquires and transmits, in real time, three axis acceleration measurements from a packing line. The WIS was tested on three apple commercial packinghouses located in the south of Brazil, and in an commercial orange packinghouse, located in interior of São Paulo state, Brazil. The WIS was submitted to all those packing lines with fruits at regular speed from the fruit reception to the packaging step. For each packing line at least four repetitions were conducted, and three levels of acceleration were considered: >10 G, > 20 G, and above 30 G. In parallel, a laboratory trial was conducted with the WIS and a commercial instrumented sphere, Instrumented Recorded Device – IRD (Techmark, Inc., Lansing, USA). The instrumented spheres were subjected to drop fall, using a dedicated equipment, from three known distances (20, 30 and 40 cm) to solid steel and two different padded surfaces, such as: polyurethane foam and courvin at a foam thickness 8 mm. The data for the three apple packinghouse showed different results as number of impacts at the three different thresholds (>10 G, > 20 G and > 30 G) and the maximum peak acceleration found. The orange packing line showed higher acceleration range peaks than the apple packinghouses. For the laboratory trial it was possible to detect different impact magnitudes among distinctive highs and surfaces. This new Wireless Instrument Sphere (WIS) showed to be an important device for measuring impact magnitude in fruit packing lines.

1. Introduction

Fruits and vegetables are very sensitive and susceptible to impact, that can occur in different stages after harvest. Sorting and grading are usually done in packinghouses, and can be an important source of fruit damage (Van Zeebroeck et al. 2007). Fruits can be subject to impact, vibration (Vergano et al., 1991) and compression forces (Pallotino et al., 2009). Post-harvest impact measurements are always a challenge (Opara and Pathare, 2014). Bollen (2006) reported that there are two alternatives for measuring fruit impact. One is sampling fruit by measuring bruising and physical damage after harvest throughout the chain and the other is using instrumentation. With instrumentation there are two procedures, one is measuring forces applied to the package and other is on the fruit. One of the most common methods applied is using pseudo-fruits. An Instrumented sphere has been used to measure impact by applying accelerometers (Opara and Pathare, 2014), especially in packing lines and the main goal is to simulate a situation to which fruits are submitted.

There have been a considerable number of instrumented spheres developed in recent years. The Instrumented Recorded Device – IRD, uses a three axis accelerometer and was developed by Michigan State University and commercialized by Techmark Inc. (Zapp et al. 1990) and has been used for measuring impact magnitude in vegetables (Ferreira et al. 2005) and fruits (Basseto et. 2006). In apples, some articles have referred its use for impact detection in packinghouses (Antoniolli et al., 2009) and for impact simulation (Sober et al., 1990) and in oranges for impact magnitude measurement (Ferreira et al., 2006) and for impact correlation with postharvest diseases (Fischer et al., 2009). There are other instrumented spheres in use. Canneyt et al. (2003), describes an instrumented sphere applied to evaluate potato impact damage and Yu et al. (2011), used one to measure berry impact. There are others dedicated to measure compression (Muller et al., 2012) and some can also measure distinctive conditions, such as temperature and humidity (Nicolau, 2009). Roa et al. (2013) describes a new Wireless Instrumented Sphere (WIS) with three axis acceleration that can be applied to measure vibrations and impacts in real time. Therefore, the main goal of this work was to evaluate the WIS in apple and orange packing lines as to its capacity for measuring impact magnitude (G). Laboratory tests were also conducted together with a commercial instrument in order to evaluate impact under controlled conditions.

2. Material and Methods

2.1 Wireless Instrumented Sphere (WIS)

The WIS circuit board was encapsulated in a transparent spherical polyurethane elastometer, 63 mm in diameter, 160 g and a 1.1 relative density (Roa et al. 2013). The WIS hardware is divided into two boards: The first encapsulated within the sphere contains: acceleration sensors, micro-controller, Radio Frequency (RF) module, battery, and connector for battery charging and on/off switching. The second is a station board connected to the USB computer port with an RF module. The software is also divided into two parts: a firmware inside the micro-controller for rate acquisition sampling, analog-to-digital conversion, data packing and transmission to the station board. The second is a Virtual Instrument (VI) with a Graphical User Interface (GUI) developed on LabVIEW software. The VI permits Real Time Analysis (RTA) and also post processing operation. The WIS uses Microelectromechanical (MEM) acceleration sensors in a three axis configuration. Two accelerometers are used for X-axis and Y-axis and one for Z-axis. The sensors range from ±1 G to ± 200 G (1 G= 9.8 $m.s^{-2}$), allowing measuring of: rotations, from ± 1 G, small impacts – vibration (±8 to ±10 G) and above ±10 G. The data collected are presented by graphs of the three-axial acceleration vectors, acceleration magnitude, velocity, velocity change, and calculate for the number of impacts (peak detection), maximum, minimum and average impact magnitude (Roa et al. 2013).

2.2 Test Trials

Trials were divided into two steps, the first being held on apple packing lines (3), located in the south of Brazil, and on a citrus packing line (1) located in the southeast of Brazil. The second step was conducted in a laboratory, applying two instrumented spheres (Commercial and WIS) to drop tests.

2.3 First step - Evaluation of impact magnitude on apple and orange packing lines

Trials were conducted on three apple packing lines, located in Rio Grande do Sul state, south of Brazil, and on a citrus packing line located in the southeast of Brazil, São Paulo State. Sorting on all three packing lines was done by imaging capture and in all, receiving occurred in a water tank. Electronic sorting was imported and the other steps were Brazilian manufactured and no wax application was present in all three. For the orange packing line, all equipment for the following steps was imported: receiving, cleaning, drying, polishing, sorting, classifying and packing. Packing lines were characterized for impact transfer points. For apple packing lines, transfer points between steps were counted and drop heights measured using a standard ruler. The drop height was considered from a 90º angle from the top of the drop to the fruit contact base. For their comparison, the total drop heights and maximum and minimum drop heights found were counted. For the orange packing line, only the number of transfer points was counted. For all, it was also observed if paddings and cushions had been applied on the packing lines. The WIS was placed together with fruits at the receiving step, following normal flow of each line until it reached packing, four times each. The measured impact was divided into three acceleration magnitude ranges (10-20 G, 21-30 G and >30 G) for comparison among packing lines.

2.4 Second Step – Laboratory Trials

In laboratory, drop tests of the two instrumented spheres were done using an impact simulator, following that described by Magalhães et al. (2007) where the spheres were individually connected by the vacuum formed in this system and dropped using a register that cuts vacuum pressure and releases the sphere. In order to measure impact magnitude, two different spheres were submitted to drop tests. The commercial instrumented sphere, Instrumented Recorded Device – IRD, 76 mm in diameter, 212 g (Techmark, Inc., Lansing, USA) and the Wireless Instrumented Sphere (WIS) 63 mm in diameter, 160 g, where individually released onto three different surfaces, rigid (solid steel), foam padded polyurethane and courvin at a foam thickness of 8 mm, at three different heights (20; 30; 40 cm), and 20 replicates for each drop height. From the data recorded, we obtained the average acceleration (G) levels for each surface.

2.5 Statistical Analyses

The multiple comparison test of Kruskal-Wallis was used to compare G distribution values in the different apple packinghouses. The Wilcoxon test was used for two independent samples to compare the distribution of G values obtained for apple packinghouses in relation to the value distributions found in the orange packinghouse. For the drop tests, the comparison of G distribution values was performed using the multiple comparison test of Kruskal-Wallis. In all cases, the significance level for all comparisons was 0.05 and the software used was Action version 2.7.28.353.495 under R platform version 3.0.2.

3. Results and Discussion

3.1 First step - Evaluation of impact magnitude on apple and orange packing lines

For transfer points characterization, it was found that apple-packing line 1 had 8 transfer impact points, with a total of 70.5 cm in drop heights, 30.0 cm being the maximum and 1.5 cm the minumum. For the apple-packing line 2, 13 transfer points were observed, and a total of 121.5 cm in drop heights and a maximum drop height of 36.0 cm and minumum of 1.5 cm. On apple-packing line 3, 9 impact transfer points were noticed, with a total of 94 cm, with a maximum drop height of 28 cm and a minumum of 4 cm. For the apple-packing lines, only the number 1 did not present padding or cushions on the transfer points. The orange-packing line showed 15 transfer points and the use of padding and cushions was noticed. The total impact number measured by WIS in the three acceleration magnitude ranges (10-20 G, 21-30 G and >30 G), was only significantly different between packing lines 1 and 3 ($p < 0.05$), according to the multiple comparison test of Kruskal-Wallis (Figure 1). For packinghouse 1, an average number of 50 impacts was observed, for packinghouse 2, 42 and for packinghouse 3 an average of 28. It is interesting to notice, that packinghouse 1, showed the highest impact number, but the lowest number of transfer points and lowest amount of total transfer heights, that can be related to the non-use of padding and cushions. The orange packinghouse showed an average of 89 impacts. The values comparison distribution of apple packinghouses was significantly different from orange packinghouse value distribution ($p = 0.005$) according to the Wilcoxon test. As known, oranges are less impact sensitive to damage than apples, which can be reason for the higher impact number for that packinghouse. Oranges also are subjected to more steps, such as wax aplication and polishing. According to the chi-square test, for all packinghouses evaluated, there are a greater proportion of impacts in the 20 G range and below, compared to values up to 20G ($p < 0.05$ for all packinghouses). Those high intensity values, in general, are caused by small impacts during sorting, which in turn, may be caused by brushing and at transfer points (Ferreira et al. 2006). For values over 20 G (average of nine impacts), there were no significant differences for impact number among apple packinghouses ($p = 0.083$) according to the Kruskal-Wallis test. However, for orange packinghouses, 27 impacts over 20 G were observed. The comparison of the distribution of the G values for apple packinghouses was significantly different from the values distribution in orange packinghouse, for the range of impacts above 20 G ($p = 0.002$) according to the Wilcoxon test. The maximum G values observed for apple packinghouse 2, apple packinghouse 3 and packinghouse 1 were, respectively, 88.9, 50.8 and 45.9 G. Packing line 2 showed the highest drop high, that can have an influence on those results. For the orange packinghouse, the maximum G observed was 69.2 G. Oranges submitted to sorting in packing lines are subjected to high impact forces (Fischer et al. 2009) that can cause physical damage. The average time expended from receiving to package was 5 min 16 s for packinghouse 1, 3 min 5 s for packinghouse 3 and 2 min 34 s for packing-house 2. In packing line 1, even having less transfer points and lower speed compared to the others, the high G can be related to absence of padding at the transfer points. For the orange-packing line the lowest value was observed: 2 min 29 s. This lowest value could have contributed to the high number of impacts (G).

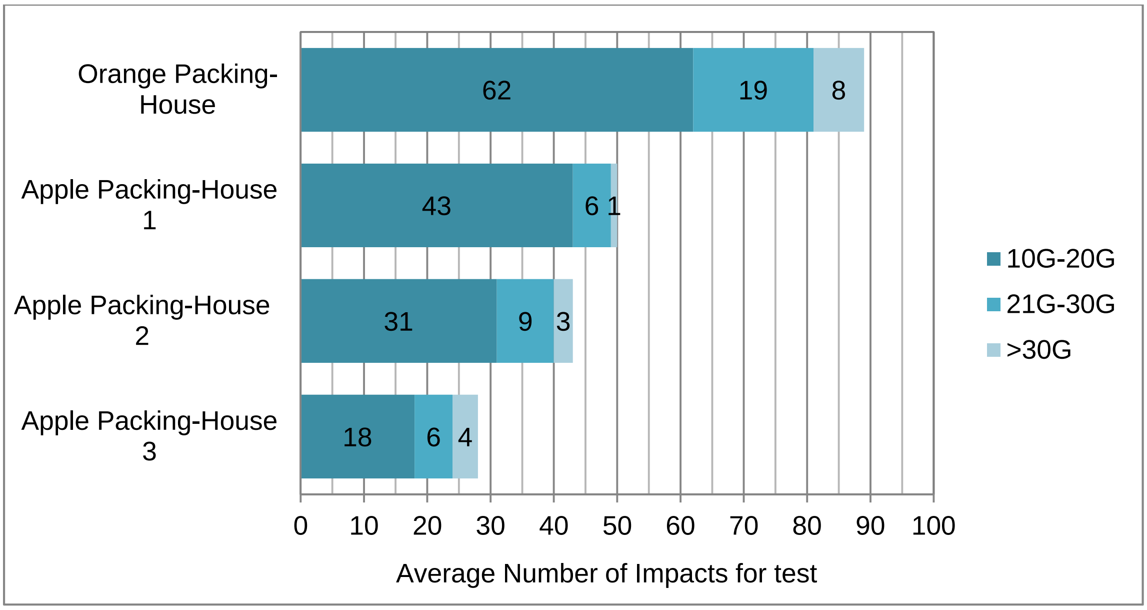

Figure 1: Average number of impacts for three acceleration magnitude ranges measured (10-20G, 21-30 G and >30G) with the Wireless Instrumented Sphere (WIS) in apple (3) and orange (1) packing-lines thru regular fruit flow

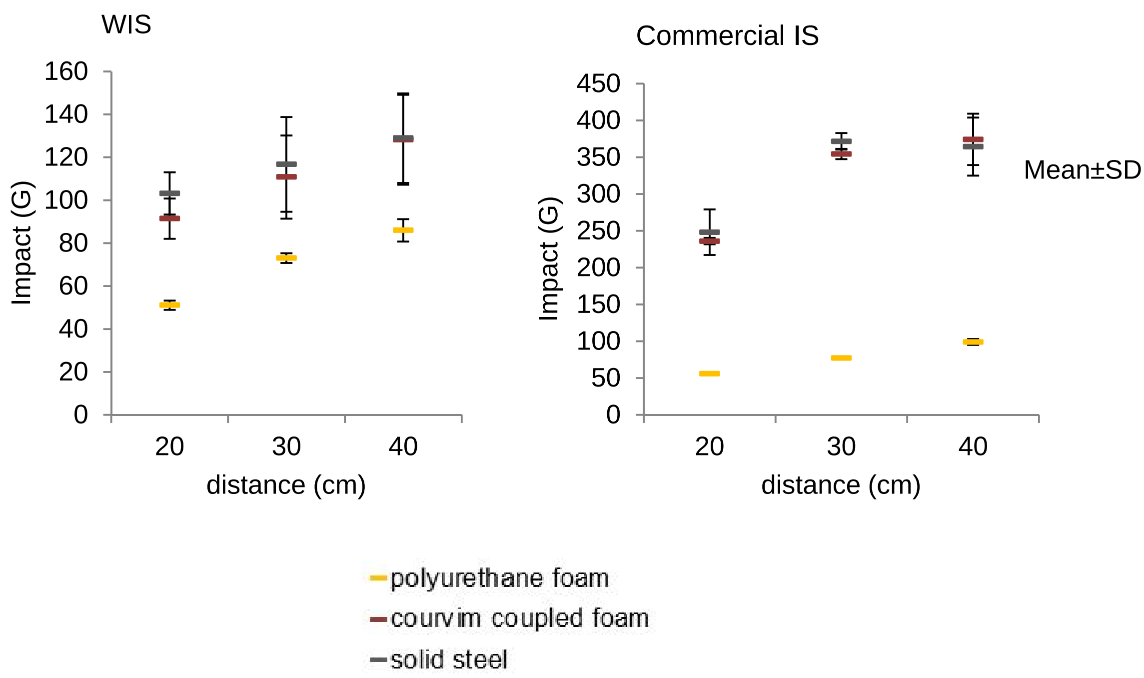

Figure 2: Drop tests on the two instrumented sphere, a commercial instrumented sphere, Instrumented Recorded Device – IRD, 76 mm (Techmark, Inc., Lansing, USA) and the Wireless Instrumented Sphere (WIS), 63 mm, on three different surfaces (steel, polyurethane and courvim coupled foam) on three different drop heights (20, 30 and 40 cm)

3.2 Second Step – Laboratory Trials

For both spheres, the commercial instrumented sphere, Instrumented Recorded Device – IRD, 76 mm in diameter (Techmark, Inc., Lansing, USA) and the Wireless Instrumented Sphere (WIS) 63 mm in diameter, in all drop heights analyzed, the G values obtained on the polyurethane foam padding were significantly different from the courvin brown foam and metal ($p < 0.001$), but there was no evidence of differences between the G values obtained on the metal bases and courvin brown foam ($p > 0.05$) (Figure 2). One of reasons is that some pads are not efficient in reducing impact forces due to not efficiently absorbing impact (Magalhães et al. 2007). It is possible to clearly observe a difference in impact magnitude values between the instrumented spheres. The highest values found for the commercial IS was close to 374.0 G and for the WIS, about 128.9 G. Those differences can be pointed out due to the material from which each one was manufactured, sphere weight, accelerometers type, etc. However, one point important to highlight is that the average G value observed for both pieces of equipment on the polyurethane padding for the highest drop (40 cm) was 2.0 times higher than the lowest drop (20 cm). For the other padding and solid steel, the proportion was similar, but not as close as that found for the polyurethane foam. Therefore, further studies are necessary for the WIS integrating the parameters mentioned.

4. Conclusions

The new Wireless Instrumented Sphere could identify differences among packing lines, showing potential use for measuring impact magnitude in Real Time Analyses. This is an important tool for Grower interface. Adjustments and developments related to size, material used and calibration reported for those features are still necessary.

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