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Embedded System for Monitoring Impact Magnitude during Orange Transport

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This paper shows the use of a new system (hardware, firmware and software) to assess the negative impact of transportation on postharvest fruit quality. Fruit and vegetable postharvest losses are very high, using this system it is possible to diagnose and implement improvements in transport, thus decreasing mechanical impact. The system has a hardware endowed with a tri-axial accelerometer and a global positioning system (GPS). The firmware of the system is composed of a threshold based detection algorithm that measures acceleration peaks during transport. The system software allows reporting impact magnitude, geographic location and time of the event on a map using a virtual instrument developed in LabVIEW ™ platform. The main goal of this research was to test this equipment in the transportation of oranges and analyze the number of occurrences when exceeding a determined acceleration threshold. Orange boxes of about 23 kg each were set on a small truck, filling the body and the equipment was positioned evenly in the back and middle. The test was done through repetition and comparison of data taking into account the position of the equipment in the truck body (back and middle) and different types of pavements on a chosen path of 20.5 km divided among unpaved, asphalt and urban avenues – with and without speed bumps and roundabouts. The chi-square test at 5 % was used for the quantitative data analysis. The results show the frequency of repetition of acceleration peaks according to their orientation (X, Y, Z axes and their combinations). For the total route, a difference was observed between the frequencies of threshold violations depending on the location of the boxes. For the chosen route, the unpaved road and urban avenues showed the highest threshold violation for vertical position - axis Z. Box position in the truck and variations in pavement causes a distinctive impact magnitude. The map showing all impact data showed to be an important tool to give support to food traceability, recording critical points and situations that can be changed.

1. Introduction

Fruits and vegetable postharvest losses are still high around world, being considered about 30 % to 40 % for both developed and undeveloped countries (Gustavsson et al., 2011). Impact, vibration (Brusewitz et al, 1991) and compression (Pallotino et al., 2009) are the most common forces that can cause postharvest fruit damage. Vibration during transport causes small impacts, which may produce bruises (Vergano et al., 1991). Bruising is the most common type of mechanical damage and it can affect income for fruit and vegetable industries because the bruising reduces the commercial appeal of horticultural production (Opara and Pathare, 2014). Methodologies to measure impact after harvest and reduce postharvest losses are an important point of study (Bollen, 2006). One possible way is to focus on measurement and analysis of vibration impact that occurs during transport using some specific equipment (Singh et al., 2006) and most current equipment allows acceleration data to be evaluated after transportation (Chonhenchob et al., 2009).

Vibration during fresh produce transport can be related to different factors, such as road roughness, truck type and speed (Jarimopas et al., 2005). Zhou et al. (2007) reported that vibration levels are variable depending on truck position, which in the rear floor was higher than on the front. Vursavus and Ozguven (2004) described that the packaging method can influence vibration levels and influence bruising incidence. Vibration levels can respond differently related to axis orientation (Hinsch et al., 1993). All those variables combined will directly affect acceleration and consequently susceptibility to vibration impacts. Castellanos and Fruett (2014) reported a new embedded system developed to measure passenger comfort in public transportation, and it was subsequently evaluated to measure acceleration during fruit transport. This system measures acceleration along different axes and gives global position coordinates. It works in combination with software that shows all impact data points on a map powered by Google Maps® embedded in a LabView® program. Therefore, the main goal of this article was to evaluate the performance of this equipment on appointing vibration impact via acceleration during a simulated citrus transportation along a route with different surface types.

2. Material and Methods

2.1 Equipment Description

The embedded system for monitoring impacts, initially developed for urban transport (Castellanos and Fruett, 2014), is composed of a hardware, firmware (algorithm) and a software. The hardware consists of tri-axial accelerometers, a Global Positioning System (GPS) module and wireless communication. The technical specification is described in table 1. The acceleration and position data are processed by a microcontroller firmware. Two algorithms using acceleration measurement are implemented in the firmware. However, one of them is exclusively for human transportation comfort assessment, which cannot be applied in this study. The one used in this study is based on the detection of acceleration peaks and Jerk magnitudes (the rate of acceleration change) using threshold values for each acceleration axis. The software is based on a Graphical User Interface (GUI) developed on a LabVIEW platform, where the events are shown on an online map interface. Also, the software provides a configuration interface that allows setting the threshold value for each axis and a download interface where the data is wirelessly downloaded.

Table 1. Technical Specification of the Equipment (Castellanos and Fruett, 2014)

Item	Description
Acceleration range	±4 G
Acceleration bandwidth	50 Hz, 100 Hz
Sample frequency	500 Hz
Maximum position accuracy	5 m
Wireless range	140 m (indoor)
Memory Type	SD™ Card
Energy consumption	250 mA
Power supply range	5V-30 V
Size	5 cm x 9 cm

2.2 Data Acquisition

The data reported by this equipment are: (a) vehicle identification, (b) event number, (c) time, (d) type and value of acceleration and, (e) position of the event. (a) The ID of the vehicle is just a user identity specification for the vehicle. (b) The event number is sequential, and refers to the event occurrence order. (c) Time: refers to the time when the event occurred. (d) Type. Type varies depending on the cause (Table 2), The amplitude (value) is related to the axes which are localize as shown in Figure 1 (e), finally the latitude and longitude are the spatial coordinates of each generated event. The acceleration is measured 500 times per second, and the maximum acceleration per second is found in each axis. Then, if this value is higher than its respective threshold value, the occurrence is reported according to the type of threshold violation together with the position and time. Event type 8 means that the temperature value is greater than the value set for the temperature threshold. The events of type 9 measure Jerk, that means the rate of acceleration change (Standard international ISO 2041,1990), and for each second maximum absolute (Jerk) is calculated on the longitudinal axis. Temperature measurement is not activated on the equipment.

Table 2. Type of Event (Castellanos and Fruett, 2014)

Event Type	Event Description
0	No event
1	Maximum X acceleration is greater them X threshold
2	Maximum Y acceleration is greater them Y threshold
3	Maximum Z acceleration is greater them Z threshold
4	Maximum X, Y acceleration is greater them X,Y threshold
5	Maximum X, Z acceleration is greater them X, Z threshold
6	Maximum Y, Z acceleration is greater them Y, Z threshold
7	Maximum X, Y, Z acceleration is greater them X, Y, Z threshold
8	Maximum temperature is greater than temperature threshold (No used)
9	Maximum Jerk is greater than Jerk threshold

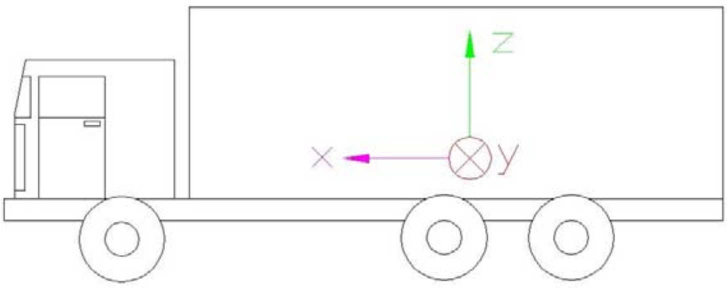

Figure 1: Orientation of axes on a truck. X (longitudinal), Y (transverse) and Z (vertical) axes

2.3 Vehicle and equipment positioning

The embedded system was applied to orange transport in a 2004 Ford, Ranger XLS12A 2.3 16V pickup truck. 21 boxes of oranges were loaded on the truck, distributed uniformly in three layers of six boxes each. Each box was filled with 23 kg, approximately 184 fruits with average diameters of 67 mm. The equipment was placed on the middle of a filled box and protected by a plastic tube on the upper dimensions of the equipment. The box containing the device was placed in the middle of the truck body, and at the rear. For each position of the equipment on the truck body (middle and back), 4 repetitions were done, for a total of 8.

2.4 Route

The trip had an extension of 20.5 km and was divided into four parts. The first part was a paved avenue, 4.5 km long, without speed bumps and roundabouts, the second part was conducted on 2.7 km of an unpaved and poorly maintained road, the third section had an extension of 7.9 km and was an asphalted highway. Finally, the fourth part was held on a paved road with 5.4 km with speed bumps and roundabouts.

2.5 Statistical methodology

For the data quantitative analysis a chi-square test was performed to compare the frequency of occurrence at a significance level of 5 %. Each type of event in the entire journey and in the individual sections was compared taking into account the equipment position. The event occurrence frequency on the four different sections was normalized for a distance of 10 km in order to eliminate the effect of section size.

3. Results and Discussions

The graphical interface visualizes the position of all occurrences. Distinctive color points indicate variations on events magnitude (Figure 2).

Figure 2: Events view using Labview Software

The data was analyzed using the described statistical methodology. For this review the charts of Figure 3 were generated. The test for comparing the sections was not performed for threshold violation with few number of occurrences, such as: for X axis for both equipment locations – middle and back; Y axis with the equipment located in the back; for X and Y axes in both equipment locations; X and Z in equipment located in the middle; and for Jerk with equipment located in the back. Comparing the frequency of event occurrences held in the trials using the chi-square test, the significant differences found are presented below.

3.1 Vertical (Z) axis

The Threshold violation on the Z axis with equipment located in the back of the truck body ($p < 0.001$) showed incidence rates of 75.3 events/10 km, 85.9/10 km, 135.9/10 km and 167.9/10 km in Sections 3, 1, 2 and 4 respectively. Therefore, Figure 3 shows that the lowest value was found on the asphalt highway, followed by the urban avenue without speed bumps and roundabouts, and the unpaved road. The highest values were on the urban avenue with speed bumps. Threshold violation on the Z axis with equipment located in the middle ($p < 0.001$) presented occurrence rates of 27.4/10 km, 134.6/10 km, 142.6/10 km and 163.7/10 km in Sections 1, 3, 4 and 2 respectively. Comparing the frequency of events related to the truck body equipment position, in Section 1 (urban avenue), a significant number of events were observed in the back position when compared with middle position, 85.9/10 km and 27.4/10 km, respectively ($p<0.001$). However, for Section 3 (highway road), there occurred more events with the equipment in the middle 134.6/10 km, when compared with the equipment in the rear, 75.3/10 km ($p<0.001$). For Sections 2 and 4, no significant differences among frequency occurrences were detected in both positions ($p=0.106$ and $p=0.156$, respectively).

3. 2 Longitudinal (X) and Vertical (Z) axes

Threshold violations on the X and Z axes with equipment located in the back ($p = 0.008$) obtained incidence rates of 2.5/10 km, 3.7/10 km, 9.3/10 km and 13.6/10 km, in Sections 3, 1, 2 and 4, respectively. The asphalt road showed the lowest value, followed by the urban avenues without speed bumps, unpaved road and urban avenues with speed bumps. Comparing the frequency of events related to equipment position in the vehicle, it was observed that for Section 2 there were a significantly higher number of events above 9.3/10 km compared to equipment located in the middle, 0.8/10 km ($p = 0.011$). For Section 4, there was no significant difference between the frequencies of occurrence for the different positions ($p = 0.074$). For the other sections, the statistics test could not be performed.

3.3 Transverse (Y) and Vertical (Z) axes

On the Y and Z axes the disruption threshold for equipment located in the back ($p<0.001$) the occurrence rates were 3.7/10 km, 7.4/10 km, 23.2/10 km and 116.0/10 km for Sections 1, 3 , 2 and 4, respectively. Urban avenues and the asphalt road showed the lowest values, followed by the unpaved road and the highest was found on the urban avenues with speed bumps. No significant difference between sections was observed with the equipment located in the middle ($p = 0.245$). However, comparing event frequencies related to the equipment position in the vehicle, a significant higher number of events was observed for Section 3, 13.6/10 km and 3.7/10 km, for the middle and back position, respectively (p = 0.018). For Section 4, there were 116.0/10 km in the back, against 14.2/10 km in middle position (p <0.001). For the other sections there was no significant difference between the frequency of occurrences in the different positions (p = 1.000 for Section 1 and p = 0.343 to Section 2).

3.4 Jerk events

For Jerk events violation, no difference was observed between sections with the equipment located in the middle (p = 0.191). For the equipment located in the back, the statistic test could not be performed. Comparing the frequency of events in relation to the equipment position in the vehicle, no significant differences were observed for Section 1 (p = 0763) and for Section 3 (p = 0.317). For the other sections the statistic test could not be performed.

3.5 Transverse (Y) axis

For the Y violation, no difference was observed between sections with the equipment located in the middle (p = 0.380). Comparing the frequency of events in relation to the machine position in the vehicle, no significant differences were observed for Section 2 (p = 0.132) and Section 4 (p = 0782).

The equipment was able to detect differences among sections and positions, and it was clear that, depending on the fruit box position and obstacles occurred (i.e.: unpaved roughness section and urban avenue with speed bumps), there would be a different interaction along the 3 axes. That can be an important issue for further studies and considerations on fruit transport.

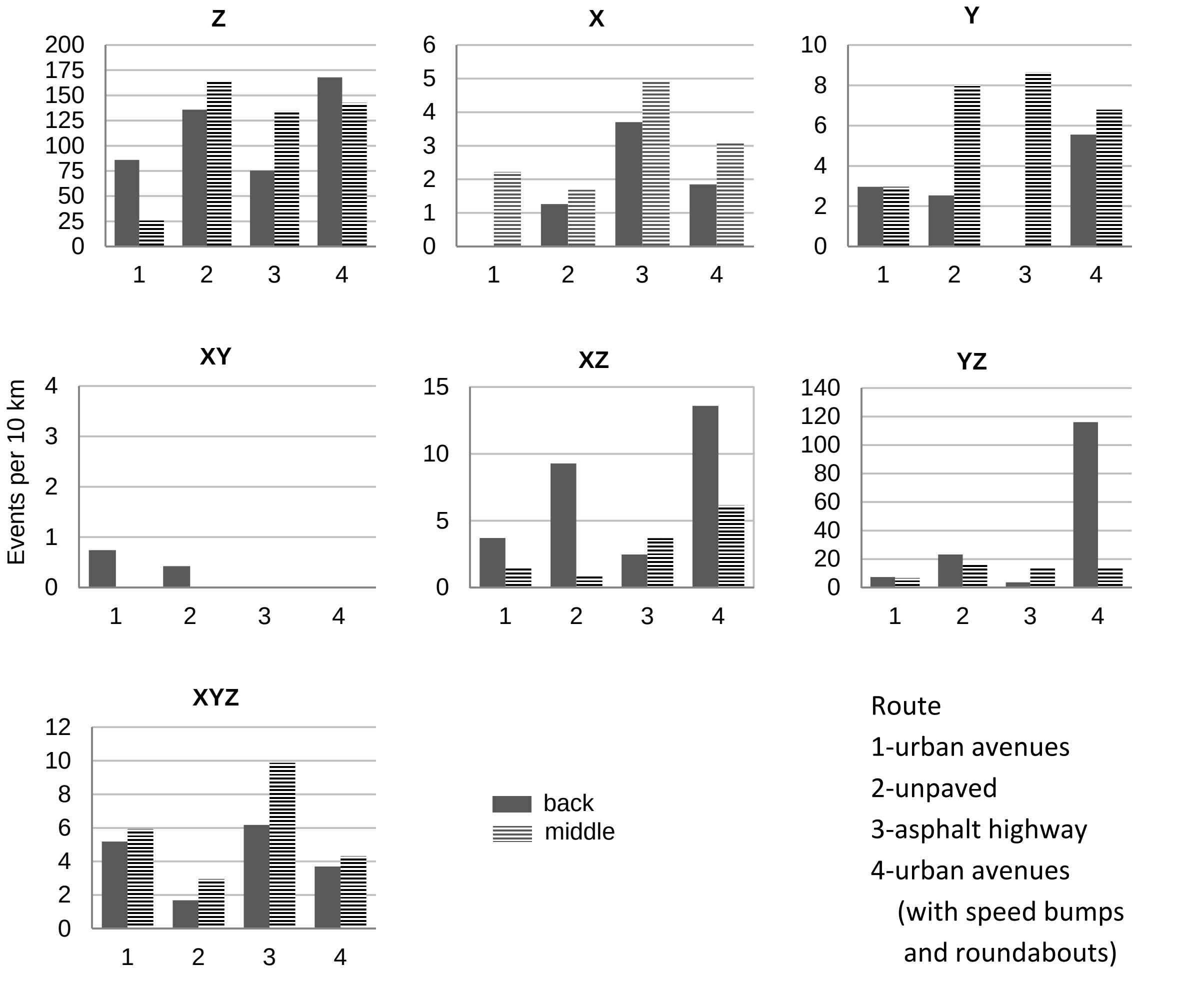

Figure 3: Occurrence rate per segment

4. Conclusions

The embedded system for monitoring impacts on fruits transport was successfully tested. It allows identifying potential impacts illustrated on a map for products by transported truck according to box position and road characteristics. An interaction between equipment position within the vehicle body and type of route section was also observed in the statistical analysis. Therefore, the system is an important tool for monitoring physical impact and contributes to fruit quality conservation, which can be applied to food transport traceability.

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