Evaluation of a localized shake-and-catch harvesting system for fresh market apples

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Abstract: Apple is a premium crop for the U.S., and fresh market apples are picked manually every year around the world, which presents challenges due to the uncertain availability and the high cost of labor-force. Mechanical harvesting is a potential solution to address these issues. A concept of localized shake-and-catch harvesting system was proposed in this study. According to our previous study, a predesigned shaking frequency was identified by achieving high fruit removal efficiency and fruit collection efficiency, and a buffered catching device with predesigned catching elevation angle was used to keep fruit bruising at a low level. The developed shake-and-catch harvesting system was then used to conduct the harvesting test with various apple cultivars trained in different canopy architectures. For tested cultivars and architectures, fruit removal efficiency varied from 66% to 95% under the shaking frequency of 20 Hz with US Extra-fancy and Fresh Market quality varying from 57% to 89%, and 78% to 94%, respectively. It was found that 'Jazz', 'Pink Lady', 'Fuji', and 'Pacific Rose' cultivars performed better in terms of fruit removal efficiency and fruit quality. In contrast, 'Gala', 'Envy', and 'Honeycrisp' cultivars were found to be difficult to remove or maintain good quality during targeted shake-and-catch harvesting. In summary, the study showed the potential for mechanical harvesting of fresh market apples for certain cultivars.

Keywords: fresh market apple, mechanical harvest, shake-and-catch, fruit removal efficiency, fruit quality, USA

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1 Introduction

Apple is one of the most valuable fruit crops in the United States. In 2014, about 130,000 ha of apples were planted nationally with approximate production values of 3 billion US dollars (USDA-NASS, 2015). Currently, hand picking is the only harvesting method for fresh market apples, which is labor intensive and costly. In the Pacific Northwest (PNW) region of the U.S., labor costs for fresh market apple and pear harvest accounts for 20% - 30% of all on-farm variable costs (Gallardo et al., 2011). This intense seasonal labor demand creates a great risk of not having a sufficient supply of farm labor at critical times to conduct time-sensitive tasks. Projecting into the future, the labor issue is expected to become more critical both in terms of increasing costs and uncertain availability (Fennimore and Doohan, 2008; Calvin and Martin, 2010). Therefore, the industry needs technological innovations to decrease reliance on manual labor and assist growers in maintaining a competitive position in the global marketplace. Mechanical harvesting is one of the potential methods to address this challenge.

Research on mechanical shaking methods for harvesting apples and other tree fruit crops dates back to the 1960s (Crooke and Rank, 1969; Tennes and Brown,

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1985; Peterson et al., 1999; Peterson and Wolford, 2003). Recently, Washington State University (WSU) has been working on a shake-and-catch harvesting system in which smaller limbs is shaken with appropriate patterns and detached fruit is collected very close to the target branches (De Kleine and Karkee, 2015). Fruit removal and fruit quality are two major concerns in the mechanical harvesting of fresh market apples. The basic principle of harvesting with a shaking mechanism is to transmit kinetic energy to fruiting branches, which is used to generate a detaching force on the fruit-stem interface to remove fruit from the tree (Erdoğan et al., 2003). During shaking, a tree would respond differently to different excitation frequencies and amplitudes, and fruit could be detached under certain detaching force with pendulum motion, tilting motion, twisting motion, or any combination of those (Markwardt et al., 1964; Crooke and Rand, 1969). Normally, the higher input vibrational energy could result in higher fruit removal efficiency but with higher level of fruit and tree damage (Norton et al., 1962). A certain amount of fruit can also remain on the tree after mechanical harvesting, which could be attributed to insufficient detaching force delivered to those fruiting locations (Diener et al., 1965).

Majority of previous studies on mechanical shake-and-catch harvesting focused on shaking the tree trunk/large branch or the entire canopies (Allshouse and Morrow, 1972; Peterson and Monroe, 1977; Peterson and Wolford, 2003). Those shake-and-catch harvesting systems are limited for commercial adoption to fresh market apples due to the excessive fruit damage caused by fruit-to-fruit, fruit-to-limb, and fruit-to-catching surface contacts during harvesting (Peterson and Wolford, 2003). As described by Pitt (1982), apple bruising occurs when the impact induced stress exceeds the fruit tissue failure stress. In order to reduce the impact induced stress, various studies have used different kind of padding materials on the catching surface (Robinson et al., 1990). Another study focused on reducing fruit falling energy by inserting foam materials to the canopy (Johnson et al., 1983). In Washington State, there are increasing numbers of orchards trained to modern trellis system providing a potential for localized shake-and-catch harvesting system to keep fruit quality to the desired level for fresh market while keeping the removal efficiency at a high level. Shake-and-catch harvesting on targeted branch/fruit section is now, therefore, more promising than ever. As fruit trees are increasingly trained towards even more uniform and planner architectures called ‘simple, narrow, accessible, and productive’ (SNAP), the ability for mechanical harvesting to achieve high harvesting efficiency with good fruit quality is in reach (De Kleine and Karkee, 2015; He et al., 2017). However, for even with the most modernized orchard architectures, the ability of a harvesting system to adapt to the many variations among tree canopies and fruit cultivars remains to be a bottleneck.

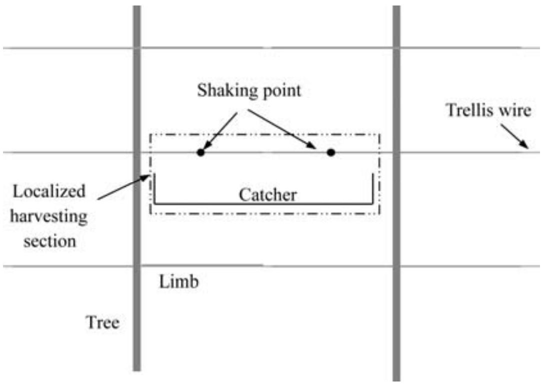
The primary goal of this study was to develop and evaluate a localized shake-and-catch harvesting system for fresh market apple with different cultivars growing on the modern trellis-trained tree architectures. Specific objectives of this study were to: (1) develop an effective localized shake-and-catch harvesting system for fresh market apples; and (2) evaluate functionality and performance of the developed shake-and-catch system in commercial apple orchards with different cultivars and tree architectures.

2 Materials and methods

2.1 Concept of localized shake-and-catch harvesting

An increasingly large number of growers in Washington State and other parts of U.S. have or are anticipated to update their orchards to SNAP architectures. For the formally trained trees (one of the narrowest SNAP architectures) with branches trained to trellis wires, one section of branch and fruit on that section could be viewed as the basic unit of the overall tree canopy. In this work, such branch/fruit sections will be used as experimental units in studying the performance of the developed shake-and-catch harvesting system. As shown in Figure 1a, there are normally six to eight trellis wires to form the tree architecture in the modern formal training system. Trees are trained relatively uniformly into horizontal layers along the trellis wires. The limbs between two tree trunks could be recognized as a localized harvesting section (Figure 1b). In this harvesting section, there are two limbs towards each other growing separately from two trees. One or two shaking points will be selected for shaking the entire section depending on the fruit removal status after shaking at one point.

a. A commercial apple orchard with formally trained architecture



b. Schematic of the localized shake-and-catch harvesting system

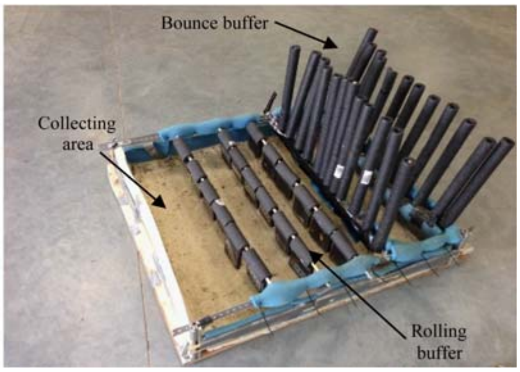
Figure 1 Illustration of localized shake-and-catch harvesting system in a SNAP orchard

2.2 Shake-and-catch system

Figure 2 illustrates the shake-and-catch system developed and used in this study. The system includes a limb shaker (Figure 2a) and a catching device (Figure 2b).

The limb shaker (Figure 2a) was adapted from a reciprocating saw (Model: 2720, Milwaukee Electric Tool, Brookfield, WI) by adding a V-shape hook. The V-shape hook allows the shaker to engage limbs with varying diameters thus ensuring efficient energy transmissibility to limbs and fruits. The developed limb shaker is compact, easy to operate and is compatible with most of the existing tree canopy architectures. The frequency of the shaker ranged from 0 to 50 Hz with an amplitude of 3.2 cm. The frequency of the shaker could be set up by adjusting the input voltage. The frequency of the shaker could be varied by adjusting the input voltage, and the relationship between shaking frequency and input voltage is shown in Figure 3.

a. A shaker adapted from a reciprocating saw with adjustable frequency



b. A catching device with buffers to reduce the speed and potential impact on apples

Figure 2 Illustration of the shake-and-catch harvesting system

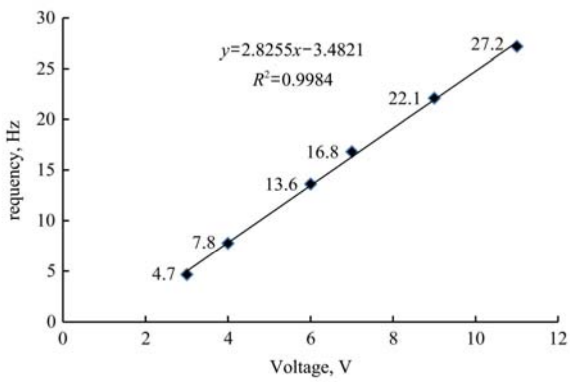


Figure 3 The feasibility of the shaker with the relationship between shaking frequency and input voltage

As shown in Figure 2b, the catching device mainly consisted of a bounce buffer, a rolling buffer, and a collection area. The catching device was built on a wood plate with a 1.5 cm thick foam (density of 44.9 $kg \cdot m^{-3}$, and pressure of 4.8 kPa at 25% compression). The base dimension of the catching device is 100 × 60 cm designed based on the space between two trees in the formal tree architecture (Figure 1b), which was used as the targeted region for shake-and-catch harvesting. As shown in Figure 4, after an apple is detached from the branch, it will drop onto the bounce buffer (Figure 4, location 2), and then landed on the foam surface (Figure 4, location 3). Since the catching surface is at certain elevation angle, the apple will roll downward to location 4. There was a rolling buffer to reduce the speed of the apple until it reached location 5 as shown in Figure 4. Eventually, the fruit will stop when it hits the edge of the catch frame (location 6).

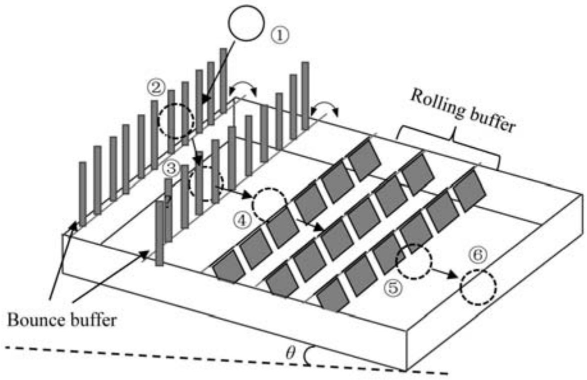


Figure 4 Fruit collection process using the catching device designed in this work

2.3 Experiment sites and experimental design

In order to assess the performance of the developed shake-and-catch harvesting prototype, field tests were carried out with different cultivars of apples produced in different tree architectures around Yakima Valley, WA during 2015 apple harvest season. The tested cultivars include: ‘Gala’, ‘Fuji’, ‘Jazz’, ‘Pink Lady’, ‘Pacific Rose’, ‘Honey Crisp’, ‘Envy’, and ‘Cosmic Crisp’. The tested tree architectures include: Vertical fruiting wall, V-trellis fruiting wall, and Bi-axis. The details on the test orchards are provided in Figure 4 and Table 1. In vertical fruiting wall (Figure 5c, e, f) and V-trellis fruiting wall (Figure 5a, b, d, h) systems, there are seven metal trellis wires to train trees in seven horizontal layers parallel to each other. In this study, only layers 2 to layer 4 were used to prove the concept. In the bi-axis system, there are two main branches for each tree (Figure 5g). In the tests, we shook each main branch of the tree as one shaking operation. A predesigned shaking frequency and an elevation angle of catching device were used for the harvesting test based on our previous studies (He et al., 2017). Certain numbers of localized harvesting sections were randomly selected for different cultivars during the field evaluation (Table 1).

a. Gala: V-trellis fruiting wall

b. Fuji: V-trellis fruiting wall

c. Jazz: Vertical fruiting wall

d. Envy: V-trellis fruiting wall

e. Pacific Rose: Vertical fruiting wall

f. Pink Lady: Vertical fruiting wall

g. Cosmic Crisp: Bi-axis

h. Honey Crisp: V-trellis fruiting wall

Figure 5 Test orchards used in evaluating the shake-and-catch harvesting prototype

Table 1 Major features of the tree in the tested orchards and test condition

Orchards	Tree planted year	Harvest date (Year: 2015)	Tree spacing, m	Branch size*, mm	Climate[#]	No. of repeats[$]
1 (Figure 2a)	2009	08/25	5.5 × 4.2	10.1	Sunny, 72F	18
2 (Figure 2b)	2010	10/10	4.9 × 3.7	14.7	Sunny, 50F	15
3 (Figure 2c)	2005	10/11	4.0 × 1.5	18.6	Sunny, 48F	21
4 (Figure 2d)	2004	10/13	4.6 × 3.0	13.8	Cloudy, 49F	16
5 (Figure 2e)	2008	09/06	4.6 × 3.0	18.4	Cloudy, 61F	15
6 (Figure 2f)	2013	10/28	4.0 × 1.5	13.5	Sunny, 48F	15
7 (Figure 2g)	2004	09/18	4.0 × 1.5	19.2	Sunny, 66F	20
8 (Figure 2h)	2013	09/08	3.0 × 2.0	10.8	Sunny, 68F	18

Note: Branch size is the average diameter of the branch at the shaking locations; [#]Climate represents the average temperature of the harvesting day; [$]No. of repeats represent the number of localized section (Figure 1b).

Figure 6 shows the harvesting test conducted in the orchard environment using the developed shake-and-catch harvesting system. First, the shaker was adjusted to the desired shaking frequency. Then we engaged the shaker to the limb and turned on the shaker. After the hook was attached at the selected shaking position of a limb, one operator held the shaker tightly and horizontally with being perpendicular to the branch during shaking operation, to efficiently transfer the vibration energy to the limbs. At the same time, another person held the catching device. After 5 s of shaking for each limb (based on our try-out test, we found that there were very few fruits being detached after 5 s), the shaker was stopped and then fruit was collected in the sampling bags. Immediately after the tests, harvested fruit samples were sent to the laboratory with room temperature (about 21°C). The quality assessment of the fruit took place after fruits were stored for at least 24 hours. Fruit removal efficiency, fruit collection efficiency, and fruit quality were estimated, and the differences among cultivars in terms of these measures were analyzed using analysis of variance (ANOVA, Duncan's method) at the significance level of $p<0.05$.

Figure 6 Shake-and-catch harvest system operating in the orchard environment

2.4 Harvesting performance measures

2.4.1 Fruit removal and collection efficiency

Fruit removal efficiency was defined as the percentage of mechanically harvested fruit against the total number of fruit growing on a test limb. The fruit removal efficiency was determined using Equation (1). Fruit collection efficiency was defined as the percentage of fruit collected by the catching device against the total number of fruit mechanically removed from a test limb as given by Equation (2). With these definitions, overall fruit recovery efficiency could be determined using Equation (3).

$$\eta_r = \frac{N_r}{N} \times 100 \tag{1}$$

$$\eta_c = \frac{N_c}{N_r} \times 100 \tag{2}$$

$$\eta_o = \eta_r \cdot \eta_c \tag{3}$$

where, η_r, η_c, and η_o are fruit removal efficiency (%), fruit collection efficiency (%), and fruit recovery efficiency (%) respectively; N_r is the number of the mechanically harvested fruit; N_c is the number of fruit collected by the catching device, and N is the total number of fruit on the test limb.

2.4.2 Fruit quality assessment

To assess the fruit bruising damage level, harvested fruits from all field tests were stored immediately in room temperature for 24 h. We went through several of quality standard/grade for fresh market apple before we conduct the quality assessment. Eventually, we picked the one that from a publication of Dr. Peterson and his colleagues who worked in USDA (Peterson et al., 2010). Fruit quality grades are categorized with the dimension of the damage area, which also widely used in the fruit packing line in

WA. In this standard, the fruit is classified into three major categories: 'Extra-fancy' (class 1 to class 4), 'Fancy', and 'Downgrade'. The percentage of 'Fresh-market' fruit is the sum of those in 'Extra-fancy" and 'Fancy" categories. In this standard, 'Extra-fancy' represents fruit bruise diameter smaller than 12.7 mm (i.e. class 1- without damage; class 2 - bruise diameter less than 3.2 mm; class 3 - bruise diameter less than 6.4 mm, class 4 - bruise diameter less than 12.7 mm); 'Fancy' represents fruit with bruise diameter between 12.7 and 19.0 mm; and 'Downgrade' represents the fruit bruise diameter larger than 19.0 mm, or fruit with punctuation or cut. The percentage of fruit in each category was defined by Equation (4).

$$\eta_d = \frac{N_d}{N} \times 100 \quad (4)$$

where, η_d is the percentage of harvested fruit in a quality category (%); N_d is the number of fruit in a quality category; and N is the total number of collected fruits in a test.

3 Results and Discussion

3.1 Shake-and-catch system inputs determination

As the detailed description in our previous study (He et al., 2017), a dynamic study was conducted to test the fruit response under different shaking frequencies by using the developed shaker. Compared to shaking frequency of 15 Hz, the fruit under vibration with 20 Hz and 25 Hz were exerted higher acceleration, especially when the fruits were located on short and big twigs. Qualitative observation in the field indicated that fruit motion under 25 Hz of shaking was more intense than other two frequencies, which might cause more fruit damage during harvest. Therefore, 20 Hz of shaking frequency was selected for all field tests conducted in this study.

Meanwhile, in order to select an effective catching elevation angle, a drop test followed with field evaluation was conducted in our previous study (He et al., 2017). The results indicated that the catching device with two buffers (bounce buffer and rolling buffer) provided the highest level of protection to the collected fruit, and catching elevation angle of 25° was relatively better than other two angles considering both fruit transfer and fruit impact strength in the catching device. Therefore, in this field harvesting test, the catching device included both buffers and was set at 25° elevation angle.

3.2 Harvest test results

The developed shake-and-catch system was evaluated in various commercial fields with different fruit cultivars and canopy architectures. The results from the tests in terms of fruit removal and collection efficiencies, and fruit quality are listed in Table 2.

Table 2 Fruit removal efficiency, collection efficiency, and fruit quality for harvesting tests (at 20 Hz shaking frequency and 25° catching elevation angle) (mean ± sd)

Verities	Canopy structure	Harvesting efficiency			Harvested fruit quality		
		Removal eff. (%)	Collection eff. (%)	Recovery eff. (%)	Extra-fancy (%)	Fresh market (%)	Downgrade (%)
Fuji	V-trellis	85 ± 10 a	98 ± 3 a	83 ± 9 a	69 ± 20 b	82 ± 13 b	18 ± 13 a
Jazz	Vertical	86 ± 12 a	98 ± 6 a	84 ± 11 a	80 ± 5 ab	94 ± 6 a	6 ± 6 b
Envy	V-trellis	66 ± 19 b	91 ± 16 a	61 ± 23 b	71 ± 14 b	82 ± 11 b	18 ± 13 a
Pacific Rose#	Vertical	85 ± 11 a	95 ± 7 a	81 ± 8 ac	74 ± 8 b	87 ± 13 b	13 ± 13 a
Pink Lady#	Vertical	88 ± 11 a	96 ± 5 a	85 ± 12 a	89 ± 9 a	94 ± 5 a	6 ± 9 b
Honey Crisp#	V-trellis	95 ± 6 a	-	-	57 ± 16 c	77 ± 18 b	22 ± 18 a
Cosmic Crisp	Bi-axis	92 ± 10 a	-	-	-	-	-
Gala*	Vertical	68 ± 18 b	100 a	68 ± 18 bc	-	-	-

Note: *for Gala, another similar shaker was used (20 Hz with 30 mm amplitude), and the harvested fruit was collected by a catching surface right below the fruits; for the rest of tests, the shake-and-catch system in Figure 1 was used; # for these three cultivars, 'ethephon' was applied to those orchards approximately 2 weeks before the harvesting test. Numbers with different letters in the same column represent the significant difference; Numbers with different letters a, b, and c have significant difference.

For the tested three architectures, since the tests were focused on the localized area (horizontal branches), there would be no difference between Vertical and V-trellis fruiting wall architectures. It was found that the fruit removal efficiency and fruit quality were depended on the cultivars. For the cultivars and architectures tested, fruit removal efficiency varied from 66% to 95% under the shaking frequency of 20 Hz. 'Gala' and 'Envy' cultivars were the most difficult to detach from branches. For other tested cultivars, removal efficiency was 80% or higher from the targeted sections. Developed catching device collected a large percentage of the harvested fruit ranging from 91% to 100%. In these experiments, percentage of fruit with US Extra-fancy quality (bruise area diameter less than 12.7 mm) varied from 57% to 89%. With some cultivars, the harvesting system achieved a good fruit removal efficiency with a good fruit quality level. For example, a fruit removal efficiency of 86% and US Extra-fancy grade of 80% was achieved for ‘Jazz’ cultivar.

Compared to ‘Jazz’ with 94% of fruits in fresh market grade, ‘Fuji’ had only 82% in the same grade, which could partially attribute to much bigger fruit size of ‘Fuji’ in our study resulting in stronger fruit impact during the fruit catching process. For ‘Pacific Rose’, ‘Pink Lady’ and ‘Honey Crisp’, hail damage occurred in those orchards during the early fruiting stage and ‘ethephon’ was applied before harvesting, which may contribute to the high fruit removal efficiency. Meanwhile, the scars from the hail damage made part of fruit surface harder, which may decrease the possibility of harvest-induced fruit damage. For ‘Honey Crisp’, we started harvesting a little bit later than usual harvesting window, which might partially influence the fruit removal efficiency and fruit quality. For ‘Cosmic Crisp’ cultivar, the tree architecture was bi-axis, with fruits mainly located in one of the big limbs, which contributed to high fruit removal efficiency of 92%. However, it was difficult to catch all the fruit using the catching device primarily developed for planner architectures. In summary, the results indicated that ‘Jazz’, ‘Pink Lady’, and ‘Pacific Rose’ cultivars performed better in terms of fruit removal efficiency and fruit quality. In contrast, ‘Gala’, ‘Envy’, and ‘Honey Crisp’ cultivars were found to be difficult to be removed or maintained a good quality during targeted shake-and-catch harvesting.

3.3 Fruit removal efficiency analysis

Fruit removal efficiency varies largely among different cultivars (Table 2). However, even for those cultivars with high removal efficiency (for example, ‘Jazz’), there are still certain amount of fruit could not be removed from the tree branches. As our previous study showed, the higher shaking frequency would increase the fruit removal efficiency, for example, fruit removal efficiency increased from 85% to 90% when the shaking frequency changed from 20 to 25 Hz, however, the fruit damage rate of the removed fruit also increased (He et al., 2017). Another factor potentially affecting the fruit removal efficiency is location of fruit in the targeted branch. In the field experiments, it was observed that majority of the remained fruits were located either far from the shaking point (shaking point is the middle of branch, fruits located close to the trunk or at the tip of the branch could not be easily removed) and/or on a long thin twig (Figure 7 as an example of unremoved fruit located at the tip of a branch and/or thin twig).

Figure 7 Fruit remain on the branch after mechanical shaking; left: fruits at a branch tip, right: fruits on long twig

In order to improve the fruit removal efficiency, suitable pruning treatment could be applied to the tree branches. In one of our test orchards (Envy on V-trellis), two different pruning treatments were applied at the dormant pruning, e.g. ‘6’ (15 mm) and ‘9’ inch pruning (23 mm) (‘6’ and ‘9’ pruning means that all the secondary branches or twig growing from the primary branch would be pruned down to ‘6’ or ‘9’ branch length). The fruit removal efficiencies were much higher when the pruning treatment was ‘6’, accounting for 78% and 58% for ‘6’ and ‘9’ pruning respectively. In another word, the fruit removal efficiency improved substantially when shorter twigs and branches were left for fruiting.

3.4 Fruit quality analysis

In order to analyze the possible fruit damage sources, three test cultivars were taken as examples to illustrate the percentages of harvested fruits in all quality levels as shown in Table 3.

Table 3 Detail fruit quality information for three test cultivars under 20 Hz shaking frequency and 25° catching elevation angle (mean ± sd)

Cultivar	Extra-fancy quality, %				Fancy, %	Downgrade (Bruise), %	Downgrade (Puncture or cut), %
	Class 1	Class 2	Class 3	Class 4			
Jazz	73 ± 7	0	0	7 ± 7	14 ± 8	1 ± 3	5 ± 5
Pacific Rose	66 ± 12	0	0	8 ± 8	13 ± 8	5 ± 7	9 ± 14
Pink Lady	71 ± 12	0	0	18 ± 4	5 ± 5	2 ± 5	4 ± 9

The majority of the fruits in Extra-fancy category were in class 1 level with certain amount of fruits in class 4 level, while no fruit were grouped in classes 2 and 3 in all three cultivars. The results indicated that if the fruit gets bruised, the diameter would generally be larger to fit into the class 2 or 3. To all three test cultivars, there were about 20% of fruits in class 4 and Fancy level combined, which means that about 20% of fruits were bruised with bruising diameter between 6.4 and 19.0 mm. In the overall 'Downgrade' level, most of fruits were in the category of puncture or cut. Generally, less than half of downgrade fruits were bruised with diameter larger than 19.0 mm. Generally, the puncture or cut happens when the fruit impacts with tree branch, while fruit-to-fruit or fruit-to-catching surface impact more likely causes bruising. Therefore, reducing the chances or strength of fruit-to-branch impact could potentially reduce the percentage of fruit in 'Downgrade' level. From our previous fruit dynamic response study (He et al., 2017), some fruits were removed with too big acceleration when they were located close to the shaking point and/or on short twigs. Those fruits removed with large acceleration had high chance to generate strong fruit-to-branch impact, resulting in higher chance of fruit damage. In our future study, gradually varying shaking frequency will be used to shake the tree branches to remove fruit gently, which has the potential to reduce the harvest induced fruit damage.

4 Conclusions

In this study, a localized shake-and-catch harvesting system was developed for fresh market apples. In order to evaluate the developed system and investigate its potential for harvesting fresh market apples, a set of field tests were conducted with fruit cultivars and tree architectures. The major findings from this study are summarized as follows:

1) Fruit removal efficiency and fruit quality with shake-and-catch harvesting highly depended on fruit cultivars, some cultivars such as Jazz, and Pink Lady were found to be more promising for mechanical harvesting in the test condition. For example, a removal efficiency of 86% was achieved with 'Jazz' cultivar with 6% of harvested fruits in 'Downgrade' level.

2) Fruit detachment efficiency was influenced by fruit location in the limb. It was observed that majority of unremoved fruits were located far from the shaking point and/or at long thin twigs. Suitable selection of shaking location (potential multiple shaking) and suitable branch pruning treatment could potentially improve the fruit removal efficiency.

In our future study, each individual fruit will be marked and the location (branch size, twig size, fruit size) will be recorded. Further analysis will then be conducted to investigate the influence of fruit location to the fruit removal efficiency and fruit quality with different fruit cultivars.

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