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Air Suspension-based Catching Mechanism for Mechanical Harvesting of Apples

Shaochun Ma*. Manoj Karkee. Han Fu***. Daozong Sun****. Qin Zhang*****

*College of Engineering, China Agricultural University, Beijing 100083, China (Tel: (86)010-62736638; e-mail: shaochun2004@cau.edu.cn).
**Center for Precision and Automated Agricultural Systems, Washington State University, Prosser, 99350,USA. (e-mail: manoj.karkee@wsu.edu).
***College of Engineering, China Agricultural University, Beijing 100083, China (e-mail: han.fu@wsu.edu).
****College of Electronic Engineering, South China Agricultural University, Guangzhou 510642, China (e-mail:sundaozong@scau.edu.cn)
*****Center for Precision and Automated Agricultural Systems, Washington State University, Prosser, 99350,USA. (e-mail: qinzhang@wsu.edu).

Abstract: Bruise damage is the most critical barrier for the application of mechanical harvesting systems for fresh market apples. One of the major source of bruising is the fruit-to-catching surface and fruit-to-fruit contact when fruit detached by harvester is collected by a catching system. In this work, a fruit catching mechanism was designed and fabricated using air suspension as a cushion to minimize fruit bruising during mechanical harvesting. Various apple cultivars with different bruising susceptibility ('Granny Smith', 'Jazz', 'Honeycrisp', 'Fuji', 'Pacific Rose', and 'Pink lady') were used to evaluate the performance of an air suspension-based catching mechanism. The results showed that fruit catching with air suspension can significantly reduce the percentage of damaged apples for all of six cultivars evaluated in this work compared to fruit catching without air suspension. It was found that the decrease in fruit damage rate with air suspension ranged from 14.5 to 36.9% for different cultivars. The effect of air suspension on the percentage of downgraded apples was not significant (compared to catching apples without air suspension) except for Pink Lady cultivar. The reduction in downgraded fruit ranged from 3% to 9.3% among different cultivars (except for Pink Lady(19%)).

Keywords: fresh market apple; mechanical harvesting; air suspension catching; apple bruises; downgraded apples.

1. INTRODUCTION

Apple industry around the world depends currently on 'hand picking' to harvest fruit from random spatial locations on individual tree canopies. In the past, research and development on mechanizing apple harvesting has focused mainly on robotic methods to pick individual fruit. However, due to lack of desired level of accuracy, speed, robustness and cost, no commercially successful robotic harvester have been available (Gongal et al., 2015). Alternatively, bulk fruit removal methods have also been investigated (Li et al., 2011; De Kleine, 2015). One of the commonly used methods for bulk harvesting has been a linear shaker used to shake the trunk or branches. Bulk harvesting has the potential to achieve desired level of speed and cost for mechanized apple harvesting. However, the method is limited by excessive fruit bruising during detachment and catching caused primarily by fruit-to-fruit, fruit-to-branch and fruit-to-catching surface impacts (Zeebroeck et al., 2007).

Researchers have conducted a series of studies on fruit catching devices to reduce the bruise damage of fresh-market fruit during bulk harvesting with mechanical shakers. Peterson et al. (2003) built upon their previous apple harvesting system and created mirrored harvesting machines, or a two-sided harvesting system. In this system, catching conveyors with padded surface were designed to intercept falling fruit and elevate the fruit to a collection conveyor. The results showed that the system achieved an Extra Fancy fruit quality of only 59%. The cushion materials used on catching surface can absorb the mechanical energy during contact, either by slowing down compression or impact, which significantly affects the fruit bruise damage (Jarimopas et al., 2007; Opara and Pathare, 2014; De Kleine, 2015). In 2011, Ortiz et al. studied three different catching surfaces (a concrete floor, an elevated canvas provided with a frame and wheels, and a concrete floor covered with a shock absorbing canvases) to assess fruit damage on citrus. The elevated canvas was the least damaging surface to fruit, indicating that shock absorbing canvases could be used to reduce fruit damage. De Kleine and Karkee (2015) also built a three-tiered catch-frame to collecting fruit removed from trellised apple trees. Plastic mesh fabric was used for apple catching at each tier. The catching devices with different types of cushion materials

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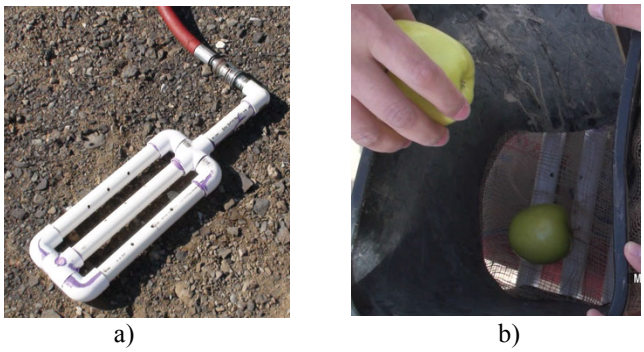
studied in the past can reduce the fruit damage caused by fruit-to-catching surface contact. However, these devices have limited ability to minimize damage caused by fruit-to-fruit contact as the fruit on the catching surface can be hit by fruit detached later. A new type of catching device is desired to address this issue.

In this work, we designed and fabricated an innovative concept of catching fruit detached by mechanical shaking devices. The catching mechanism designed in this work included air suspension as a cushion to decelerate (to reduce the contact force between fruit and catching surface) and separate (to reduce fruit-to-fruit contact) fruit before that reach the catching surface. The objective of this paper was to evaluate the performance of air suspension-based catching mechanism in reducing bruise damage levels on fruit harvested in modern apple orchards.

2. MATERIALS AND METHODS

2.1 Air Suspension Catching

Before developing the fruit catching prototypes, we designed an air suspension platform (Fig.1a) and set up a series of lab tests to evaluate the air suspension catching concept (Fig.1b). A total of 30 pairs of apples (Golden Delicious) were used to perform the apple-to-apple impact test (Fig.2). Half of the samples (15 pairs) were used for the test with pressurized air (690 Kpa). In this case, an apple was suspending above the platform and another apple dropped from the height of 0.6 m impacting the suspended apple. Another 15 pairs of apples were used for the test without pressurized air. In this case an apple was dropped from a height of 0.6 m to impact another apple placed on the platform without air suspension. All apples were marked and stored for 24 hrs before they were analysed for damages (bruising). The results showed that the damage rate can reach up to 75% without air suspension while the damage rate can be reduced to as low as 16.7% when the pressurized air was used to slowdown and suspend apples. The results showed that air suspension could substantially reduce impact force in the event of apple-to-apple contacts.



a) b)

Fig.1. a) Air suspension platform; b) Apple-to-apple impact test

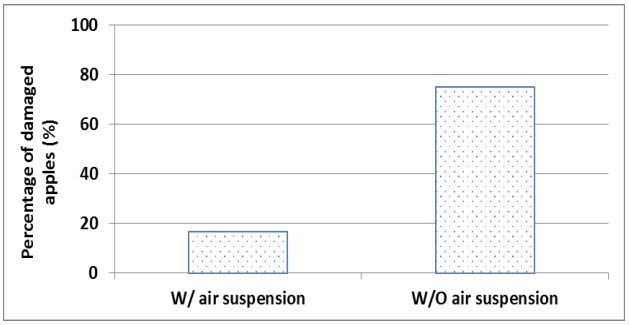


Fig. 2. The effect of air suspension on apple damage percentage

Thus, the fruit catching mechanism (Fig. 3) was designed to incorporate the following two critical functionalities: (1) decelerate the fruit falling from branches; and (2) separate fruit before they land on the catching surface. These two functionalities are essential to reduce fruit damage and to achieve desired level of fruit quality during mechanical harvesting. The first prototype of the catching mechanism was fabricated and evaluated during 2015 apple harvesting season in Washington State (Yakima Valley Orchards, Othello, WA). Two air hose couplers (component 2) are used to connect air inlets of catching mechanism to air compressor outlets. Once the hoses are engaged and air compressor is turned on, an air cushion will be generated for decelerating and separating falling fruit. When the air compressor is turned off, the scattered fruit could be landed on the foam surface (component 4) slowly. In addition, the catcher wall (component 1) is used to prevent apples from falling out of the air cushion boundary.

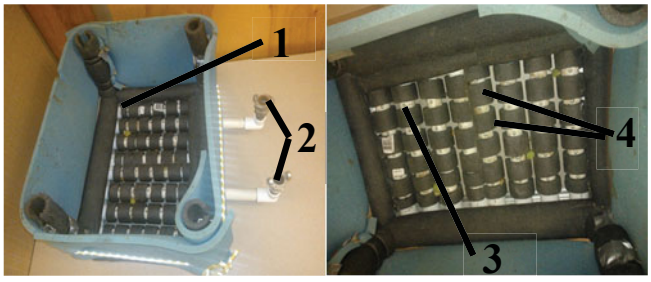


Fig. 3. Overview of the conceptual design and prototype of the air suspension-based fruit catching mechanism; 1. Catcher wall; 2. Pressurized air inlet; 3. Air outlet holes on PVC pipe; 4. Foam cushion

2.2 Fruit Catching Process

During apple harvesting process, the pressurized air blown out from small nozzles on the PVC pipes generates an upward force to decelerate the apples accelerating down from the branches. The risk of apple bruises caused by apple-to-apple or apple-to-catcher contact will be decreased because of reduced impact force. As the falling fruit reach the zone with blown air, the fruit clumped together in a random fashion are separated, which minimizes impact with each other leading to reduced level of fruit damage.