

A REVIEW OF BIN FILLING TECHNOLOGIES FOR APPLE HARVEST AND POSTHARVEST HANDLING



Z. Zhang, A. K. Pothula, R. Lu

ABSTRACT. *Bin fillers play a critical role in transporting and distributing fruit evenly and without bruising into individual bins or containers from harvest platforms infield or sorting lines in the packinghouse. Over the years, a large variety of bin fillers have been developed for infield use and postharvest handling. This article reviews different bin filling technologies in terms of major design features, performance, and throughput, as well as automatic control and safety features. For infield use, bin filler designs have evolved from the early use of conveyors and reciprocating plates to recent adoption of soft pads and foam rollers, to reduce bruising and improve fruit distributions. For postharvest use, tilted bins and conveyors commonly used with early bin fillers have been replaced with hinged trays and vacuum suction cups for fruit transport and cylinder brushes and swingable dividers for bruise prevention. While many types of bin fillers have been developed, few are suitable for infield use because it imposes more constraints than postharvest use. Despite the use of automatic sensing and control in most bin fillers, human assistance is still needed during their operation. There are still major issues with the current bin fillers, such as large size, complexity in design, uneven fruit distributions, and low throughput. Further effort should, therefore, be directed towards the development of high throughput, simple yet reliable, compact and fully automated, or even intelligent bin fillers for infield and postharvest use.*

Keywords. *Apple, Automation, Bin filler, Harvest, Infield, Postharvest handling.*

Apple is one of the most favorite fruits worldwide because of its distinct nutritional and textural properties and desirable taste or flavor (Boyer and Liu, 2004). In 2016, the global apple production was approximately 9×10^7 MT (FAO, 2016). The United States is the second largest apple producing country behind China; it produced 5×10^6 MT of apples in 2016 (USDA, 2017). In the United States, harvest and postharvest handling (i.e., storage, grading, sorting, and packaging) account for more than 50% of the total apple production cost (Seavert et al., 2007; Baugher et al., 2009; Gallardo et al., 2010; Gallardo and Galinato, 2012; Galinato et al., 2014). Consequently, technological innovations in harvest and postharvest handling to lower the overall production cost are considered to be a top priority for the U.S. apple industry in order to maintain its competitiveness in both domestic and international markets.

Currently, manual harvesting of apples is still the prevailing method, which is low in productivity, high in labor cost

(especially for many developed nations), and physically demanding or even hazardous for workers. As labor cost and availability is becoming an increasingly serious issue, there is an urgent need for harvest mechanization and automation for the U.S. apple industry (Hansen, 2009; King, 2012). However, the development and adoption of commercially viable mechanical or fully automated (i.e., robotic) harvest technologies has been hindered by such major issues as low harvest efficiency (related to robotic harvesting), high machinery cost, and excessive bruising damage (Zhao et al., 2011; Davidson et al., 2016a, 2016b; He et al., 2016; Xu, 2016). Hence we have seen increased use of harvest platforms recently by apple growers in the United States and Europe, as an immediate, practical solution to increasing harvest productivity, decreasing manual strength requirements, and alleviating occupational injuries (Schupp et al., 2011; Luo et al., 2012; Zhang, 2015). Though varying in designs, these harvest platforms can be largely divided into two categories: with or without conveyors (Clark, 2015; Jones, 2015; Munckhof, 2016; Zhang et al., 2016b). For the conveyor-equipped platforms (mainly made in Europe), pickers directly place harvested apples on conveyors (or vacuum tubes) that automatically transport them to the bin filler, which receives and disperses the fruit in the bin. For non-conveyor harvest platforms (largely made in the United States), workers still need to carry buckets or bags for temporarily holding harvested apples till full, and then dump the apples in the buckets into the bin carried on the platform. Compared to non-conveyor versions, the platforms installed with conveyors (or vacuum tubes) can further improve harvest productivity, decrease strength requirements, and reduce occupational injuries (Freivalds et al., 2006; Zhang

Submitted for review in February 2018 as manuscript number MS 12827; approved for publication by the Machinery Systems Community of ASABE in May 2018.

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et al., 2014; Zhang, 2015). A key reason for the existence of non-conveyor harvest platforms is lack of appropriate in-field-use bin fillers and high equipment cost associated with the incorporation of bin fillers. Moreover, there still are some major technical or functional deficiencies with many current commercial infield bin fillers, such as lower harvest efficiency (due to interruptions to the harvest crew when loading and unloading bins), lack of automation, excessive fruit bruising, and uneven fruit distributions in the bin (Zhang et al., 2017b). Therefore, it is critical that appropriate bin filling technology for infield use be developed, which would meet such requirements of high throughput, low cost, compact design, no or minimum bruising, and uniform fruit distributions, so that apple growers can receive greater benefits from using harvest platforms (Lehnert, 2013).

Bin fillers are extensively adopted during postharvest handling for delivering fruit from conveyor belts or sorting lines to bulk bins. Individual bins filled with harvested apples are transported into the warehouse, and they will be kept in controlled atmosphere or refrigerated storage until packaging for the fresh market. Many packinghouses in the United States presort apples into individual bins prior to long-term storage (Mizushima and Lu, 2011; Kahn, 2015; Zhang et al., 2016c; Lu et al., 2018). Presorting separates apples into different quality grades and then repack the fruit in individual bins for storage. Bin fillers are used to refill individual bins with different grade apples. If bruised or mechanically damaged during the bin filling, the apples would be susceptible to disease or mold infection and subsequent decay during storage, which could potentially incur enormous loss for growers and packinghouses (Brown et al., 1989). It is therefore critical that bin fillers be such designed that they do not cause bruising damage to apples during the filling process. There are two types of bin fillers for postharvest handling, i.e., wet and dry (Peterson et al., 1999; Peterson et al., 2010). Compared to wet bin fillers, which take advantage of fluid (usually water) as a carrying medium to place fruit into the bin, dry bin fillers use mechanical methods (e.g., spinning pinwheel) to deliver fruit into the bin. Wet bin fillers, which require large space and high initial capital investments, are susceptible to the spread of disease inocula from infected to non-infected fruit, and also have the issue of wastewater disposal (Main and Main, 1997; Peterson et al., 2010; Schupp et al., 2011). The adoption of wet bin fillers is partly attributed to the lack of appropriate dry bin filling technology with desirable performance in terms of cost, bruising prevention, fruit distributions, and throughput. Since wet bin fillers are limited to presorting use, they are not covered in this review. Instead, the current review is primarily focused on the dry bin filler, and hence the term *bin filler* mentioned hereinafter is referred to the dry type, unless otherwise specified.

Until now, a large variety of bin fillers have been developed for packinghouse use, while only a few are specifically developed for harvest platforms. Many commercial bin fillers, as described in the following sections, still cannot fully meet the needs of end users in terms of performance and cost. With increased use of harvest platforms, especially those with conveyors, along with the development of infield sorting technology, there is a critical need for new bin filling

technology suitable for use with various harvest platforms. This article provides a first, comprehensive review of various bin filling technologies developed over the past decades, by categorizing them into infield and postharvest. After an overview of the major features of each bin filling system, its merits and limitations are discussed and summarized in terms of performance, compactness, design complexity, and automation features, as well as throughput and safety considerations. Moreover, a brief review is also given of the major automatic control systems used for different types of bin fillers. It is hoped that this review will provide comprehensive information and as a valuable reference to help researchers and practicing engineers in the development of new generation bin filling technology for meeting the ever increasing demands from apple and other fruit growers and packinghouses for harvest, infield sorting, and postharvest handling. While cost is an important factor in the development and adoption of bin filling technology, the cost analysis was not considered in this study.

BIN FILLERS FOR INFIELD USE

Infield bin fillers are incorporated into harvest platforms to automatically catch apples at the end of conveyors and then place them into the bin. In addition to being compact to fit with a specific harvest platform, the bin filler should be cost effective. The filling operation should be fully automated with minimal or no human assistance. In the following sections, commercial bin fillers that are currently being used with different types of harvest platforms are first presented, followed by those that were or are being developed by researchers, but have not been commercialized.

COMMERCIAL BIN FILLERS

Prototype

The DBR apple harvester (Phil Brown Welding Corp., Conklin, Mich.) has recently been commercialized in the United States, which uses vacuum tubes to transport fruit. A specially-designed bin filler, consisting of two decelerators and a pinwheel (fig. 1), is used with the harvester for receiving apples from the vacuum tubes and then placing them in the bin. High speed apples transported in the vacuum tubes are decelerated significantly by the decelerators, after which

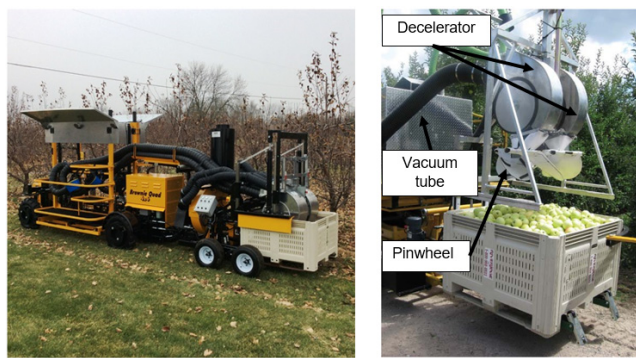


Figure 1. DBR vacuum apple harvester (left) with a close-up of the bin filler (right) (Lehnert, 2010; Phil Brown Welding Corp, Conklin, Mich.).

they arrive at the spinning pinwheel. The pinwheel, consisting of four soft and flexible pads, not only further decreases fruit speed, but also distributes them evenly in the bin. A linear actuator is used to lift the unit of pinwheel and decelerators to realize automatic filling.

The Pluk-O-Trak apple harvester (Machinefabriek, Horst, The Netherlands), using fingered conveyors to transport harvested fruit, has been on the market for European and U.S. apple growers. A specially-designed bin filler has been incorporated into the harvester, including a vertical endless fingered belt, a cylinder brush, and a padded panel (fig. 2). Workers pick apples from the tree and place them onto the side conveyors, which are then transported to the main conveyor. The bin filler, which catches and then holds and transports the fruit downward with fingered conveyor, is mounted at the end of the main conveyor. A swingable padded panel, immediately beneath the vertical belt, is used to reduce the apples' speed as well as to detect the fruit level in the bin to determine if lifting of the bin filler is needed. By pushing apples away from the panel, the cylinder brush prevents fruit congestion at the panel and also leaves buffering room for the next row of arriving apples. Both the cylinder brush and bin are spinning under working conditions to assist with even distributions of fruit.

The Revo apple harvester (Revo S.R.L., Ciampagna, Italy) employs a design concept similar to that of the Pluk-O-Trak apple harvester, in which projection-attached conveyor belts are used to transport fruit. Compared to the Pluk-O-Trak, in which apples need to drop from the main to the vertical conveyor, the Revo uses one single wave belt. The one single belt design eliminates the transitional phase of apples dropping between belts. When apples drop between two belts at high speed, they have a good chance to be bruised, which would, in turn, constrain the conveyor's speed and thus limit the system's throughput. Therefore, the system's throughput could be improved by adopting one single belt.

The spinning cylinder brush and bin, and the apple level detection panel have the same functions as those in the Pluk-O-Trak harvester's bin filler.

Advantages and Limitations

The commercial infield bin fillers generally handle apples gently, with satisfactory performance in bruising prevention (Daly, 2013; Robinson and Sazo, 2013). One major advantage of the pinwheel design is its simplicity (fig. 1). However, the pinwheel was found to result in uneven fruit distributions in the bin and its automatic lifting function did not perform satisfactorily (personal observations during an orchard demonstration in Sparta, Mich., on 6 October 2015). While the automatic lifting function performs satisfactorily and fruit are distributed uniformly in the bin, the major concern of the Pluk-O-Trak and Revo bin fillers (fig. 2 and 3) is the use of the bin spinning approach. Since each bin weighs approximately 400 kg when fully filled, the bin spinning design could pose potential safety issues when the harvest platform travels in varying orchard terrains, some of which are quite rough or steep. Moreover, these bin fillers take up much space, and hence it is not practical to install two or more bin fillers on a single harvest platform, which would be needed when the platform is integrated with the infield sorting system. Another major issue with these fillers is that when the bin is filled, human assistance is needed to remove the full bin and move into place an empty one. Consequently, the harvest crew has to temporarily suspend the picking activities, which would negatively affect the overall harvest productivity.

RESEARCH BIN FILLERS

Prototype

In addition to the commercial bin fillers discussed above, several versions have been developed by researchers, but not yet in commercial use. O'Brien (1966), Van Wijngaarden and Weterings (2004), and Wickam and Perkins (1974) each

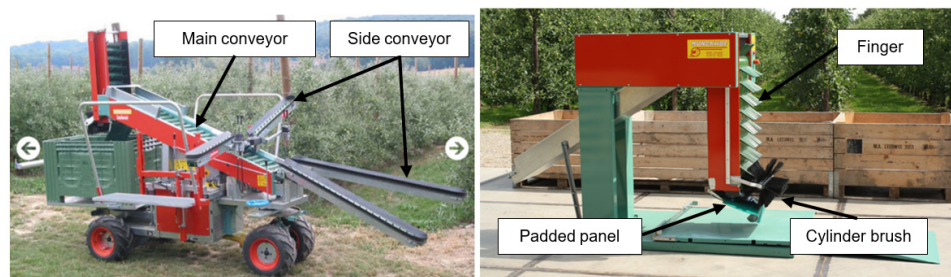


Figure 2. Pluk-O-Trak apple harvester (left) with a close-up of the bin filler (right) (Munckhof, Horst, The Netherlands).

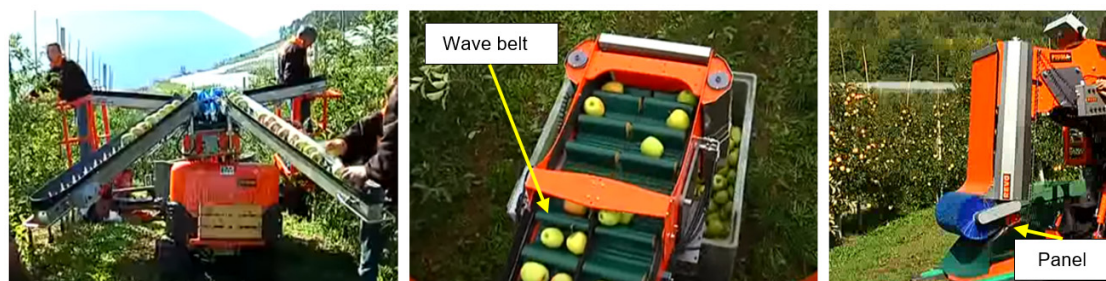


Figure 3. Revo apple harvester (left) with a close-up of the single wave belt (middle) and bin filler (right) (Revo, Ciampagna, Italy, 2016).

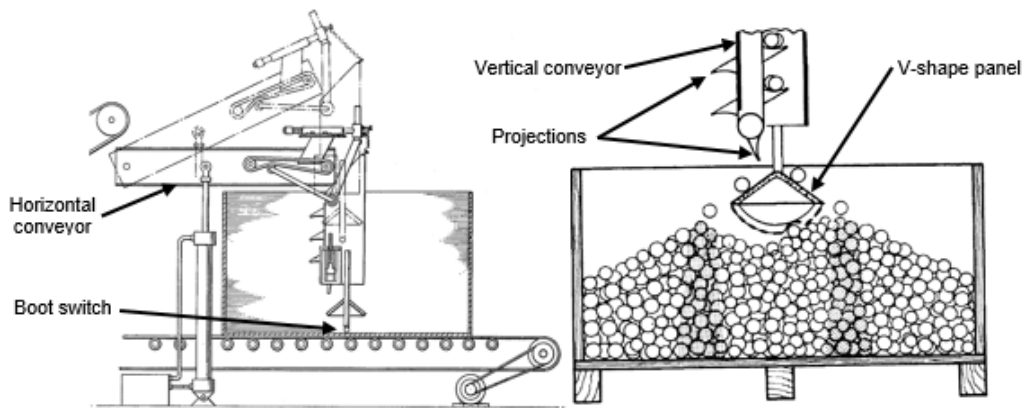


Figure 4. Automatic bin filler (left) and when it is in operation filling fruit into the bin (right) (O'Brien, 1966; 1967; 1969).

developed a fruit bin filler using a similar concept, mainly consisting of two conveyors (fig. 4). The vertical conveyor catches apples at the end of the horizontal (or inclined) one and then holds and delivers them to the bin via a series of projections. Instead of falling into the bin directly, fruit first collide with a V-shape panel to have kinetic energy absorbed partially. The increased fruit level in the bin will push the boot switch, which activates a hydraulic cylinder to lift the bin filler (phantom lines in left picture show another bin filler position). O'Brien (1967; 1969) and Paasch and O'Brien (1981) incorporated this bin filler into a mechanical harvester, and the right schematic in figure 4 shows the bin filler in operation mode, filling fruit into a bin infield, which resulted in non-uniform fruit distributions and potential fruit damage.

O'Brien (1968) developed a webbing bin filler, in which fruit are lowered by sifting down through a maze of webbings arranged alternately in successive levels. The fruit is decelerated through collisions with webbings, and when fruit arrive at the final place in the bin, they have a very low speed. The multiple webbings separate a single long-distance drop into multiple small-distance drops to avoid bruising. As fruit are filling the bin, the filler is raised manually and gradually.

Mehlschau (1968) invented a bin filler with one stationary section and one pivotable portion (fig. 5). At the initial stage of filling, the discharge head is close to the bin bottom to reduce fruit drop distance. As the bin is being filled, the

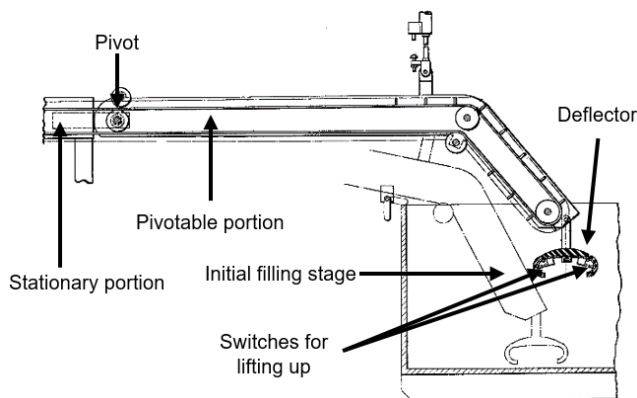


Figure 5. Bin filler with a swingable deflector (Mehlschau, 1968).

pivotable portion is lifted accordingly. A deflector, swinging freely like a pendulum, is mounted beneath the end of the fruit discharge belt to absorb fruit's kinetic energy during collisions and distribute fruit uniformly. Once pushed by the accumulated apples in the bin, the switches attached at the deflector bottom will activate the system to lift the bin filler's pivotable portion. Although it had been incorporated into an experimental fruit harvest machine, the bin filler's performance was not reported (Fridley, 1970).

The positive-transfer conveyor bin filler (fig. 6), developed and tested by Berlage and Yost (1969) and Phillips Jr. and Curlee Jr. (1962), was incorporated into an apple harvest machine by Berlage and Langmo (1974). This bin filler consists of two rubber-coated fabric belts padded with polyfoam, with a gap between belts smaller than the fruit diameter, so that they can hold the fruit while conveying them downward. Underneath the gap, two opposite-direction, spring-loaded exit gates guide fruit into the bin. The spinning speed adjustable bin approach could realize zero (or minimal) relative velocity between the apples being discharged into the bin via exit gates (shown in fig. 6) and those already in the bin, thus minimizing or preventing bruising occurrences. As filling is going on, the fruit in the bin push the exit gates up, which activates a micro switch to lower the spinning bin automatically, so as to keep a constant distance between the exit gates and the apple level in the bin.

Millier et al. (1973), Rehkugler et al. (1976), and Millier

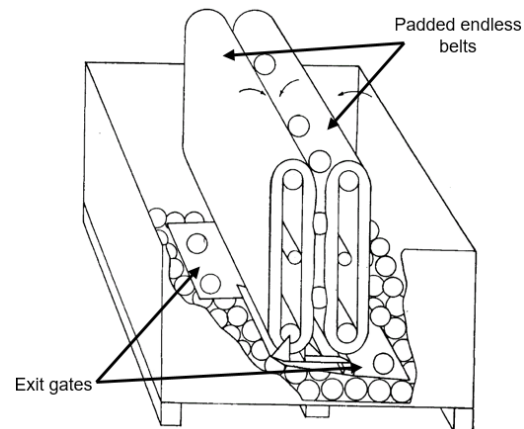


Figure 6. Positive-transfer conveyor bin filler (Berlage and Yost, 1969).

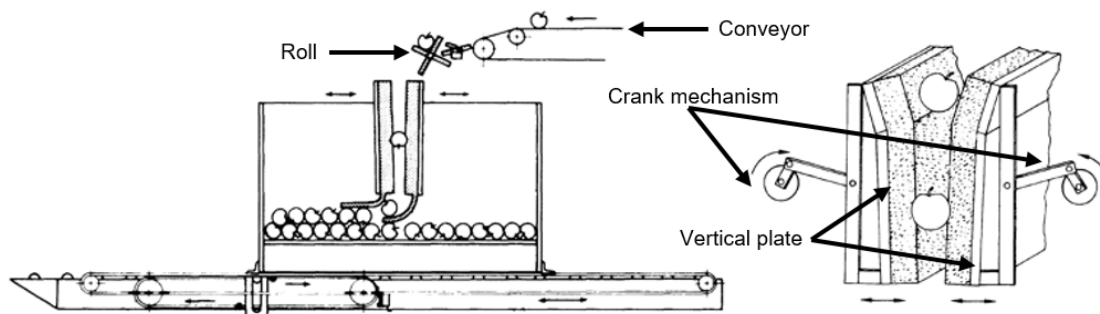


Figure 7. Grabber bin filler (left) and a close-up view (right) (Millier et al., 1973; Rehkugler et al., 1976).

et al. (1978) developed and patented a grabber bin filler (fig. 7), and finally incorporated it into an apple harvester. The grabber bin filler consists of a conveyor, a roll, two crank mechanisms, and two vertical plates. The roll catches apples from the end of the conveyor, and then drops them into the gap between the two vertical plates row-by-row. The two vertical padded plates, driven by the two synchronized crank mechanisms to reciprocate in the horizontal direction, alternate grabbing and releasing actions to transport fruit downward. The grabbing and releasing actions could be realized because the horizontal distance between the two panels varies sinusoidally as a function of time. The bin reciprocates horizontally to achieve uniform apple distributions with a layer-by-layer filling format. Field tests demonstrated uniform distributions of fruit, but bruising and system throughput were not reported.

Berlage (1981) developed a distribution-pan bin filler, and Peterson et al. (1997) incorporated it into an apple harvest platform. The bin filler discharges apples promptly from the pan to the bin as it rotates continuously (through centrifugal force) while maintaining tilted (through gravity). Soft floating pads, attached at the discharge gate, are used as a cushion between apples exiting from the gate and those in the bin.

Peterson and Wolford (2003a, 2003b) developed and patented a bin filling apparatus (fig. 8), which was incorporated into a harvest-assist platform (Peterson and Wolford 2002; Peterson, 2005). The bin filler includes a projection-attached vertical conveyor, a chute, and a spinning cylinder brush. Installed at the end of the chute is the cylinder brush, which reduces fruit speed and improves the fruit uniformity before arriving at the vertical conveyor. The bin spinning method is used to achieve uniform fruit distributions, and the bin filler's automatic lifting function is realized through a flap which would be pushed upward as the fruit level rises.

Kliethermes et al. (2010) proposed the concept of using an energy absorbing grate for a passive bin filler. By allowing workers to dump apples in the bucket into the bin without excessive bodily bending, this design would alleviate potential physical injuries to workers. Before contacting apples already in the bin or bin floor, falling apples collide with the grate (rubber bands and foam balls) to have most of their kinetic energy absorbed. The same authors further proposed another bin filler design based on a pneumatic self-adjusting bladder concept (fig. 9). It mainly consists of a series of adjacent and alternating inflation and deflation cylindrical

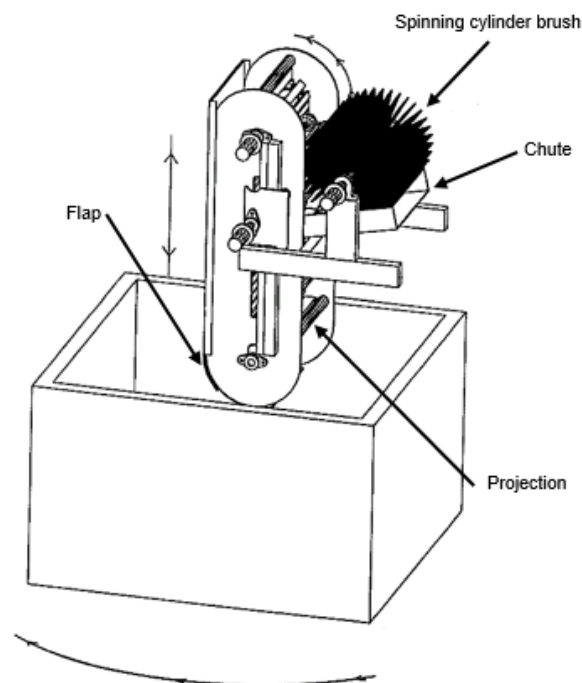


Figure 8. Bin filler with a cylinder brush to decelerate fruit and achieve their uniformity upon arriving at projections (Peterson and Wolford, 2002, 2003a).

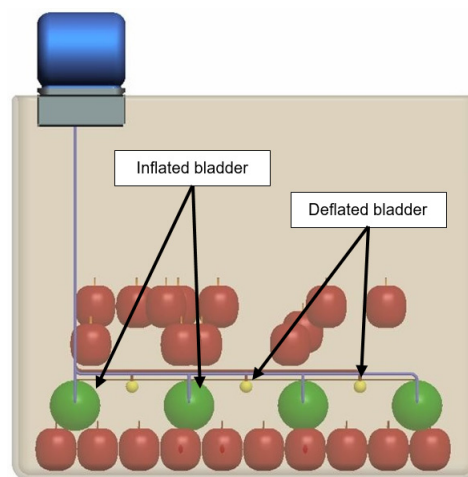


Figure 9. Concept of pneumatic self-adjusting apple bin filler with an alternate bladder inflation and deflation system (Kliethermes et al., 2010).

bladders, which not only perform as a cushion layer to decelerate falling apples, but also automatically push the bladder system up the rising pile of apples. Though interesting, these proposed concepts have not been turned into practical bin fillers.

Zhang et al. (2014, 2016a) and Zhang and Heinemann (2017) developed a cone-shaped bin filler and incorporated it into a low-cost apple harvest-assist unit (fig. 10). Apples are first transported into the bin filler via gravity, then collide with the padded cone to lose kinetic energy partially, and finally are discharged by the spinning floating pads with low speed. The spinning floating pads allow fruit to be distributed uniformly, and the lifting function is realized by a linear actuator, coupled with an IR sensor which collects apple height information in the bin. Field tests at the throughput of 1.6 apples/s indicated that 97% of apples were graded Extra Fancy (Note: apples for this quality grade should have either no bruising or total bruising areas smaller than 127 mm² so as to meet the fresh market requirements established by the U.S. Department of Agriculture). Zhang et al. (2017a) further developed a cylinder brush mechanism for the same apple harvest-assist unit in order to decrease apples' speed and improve their distributions. As apples are dropping onto the brush, its rigid but resilient bristles effectively decrease the speed of apples. By the time arriving at a soft padded panel before hitting other apples or the bare floor of the bin, apples would have a very low speed. Field tests of this improved bin filler demonstrated that more than 95% of apples were graded Extra Fancy.

A new bin filler was recently developed for an apple harvest and infield sorting machine (fig. 11) (Zhang et al., 2017b, 2017c, 2017d). After being singulated and passing the machine vision inspection chamber, apples fall freely into a pair of spinning foam rollers, which decelerate the fruit and then distribute them in the bin uniformly through a spinning pinwheel mounted with floating pads. The guiding curtains are used to ensure apples fall into the gap between the foam rollers, and the guiding sliders function as a track for the bin filler's vertical movement. The filling process is monitored by one Hall Effect sensor and one IR sensor, which record the spinning speed of the pinwheel and the apple level (via the floating pads), and the onboard microcontroller then sends signals to activate the linear actuator to lift the bin filler automatically. Lab test showed that 97% of 'Gala' apples handled by this bin filler were rated as Extra Fancy.

Advantages and Limitations

Cushioning panels (V-shaped panel or deflector) in the bin fillers presented in figures 4 and 5 decelerate fruit via collisions before contacting other fruit. However, the early arrived fruit would generally mound at the center of the bin, and hence latter arriving fruit need to roll a long distance to reach their final places, during which bruising may occur. Despite the fact that collision magnitude is significantly reduced by breaking one long-distance drop into multiple small-distance drops in the webbing bin filler, some apples do not contact the webbings but drop directly onto apples



Figure 10. A low-cost apple harvest-assist unit (right) mounted with a bin filler (left) (Zhang et al., 2014, 2016a).

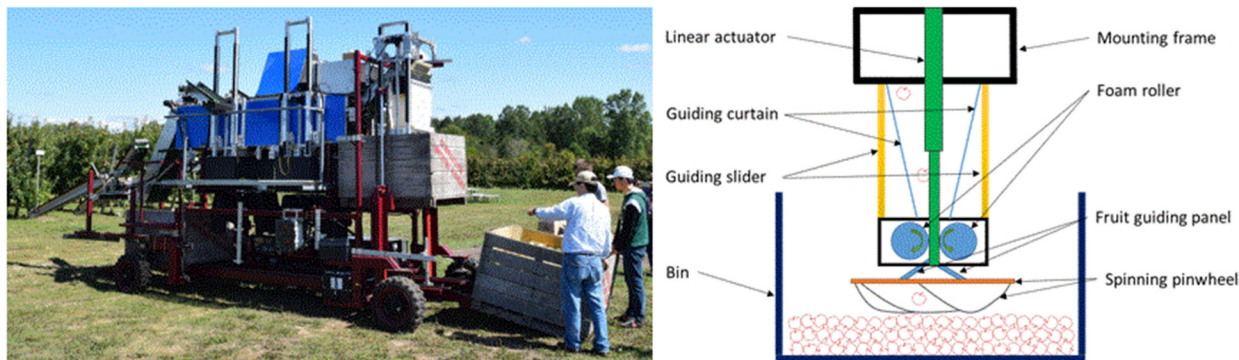


Figure 11. Bin filler mounted in an apple harvest and infield sorting machine (left) and its schematic (Zhang et al., 2017c).

already in the bin, because the webbings are afloat. The positive-transfer conveyor shown in figure 6 could keep relative minimal velocity between late arrived apples and those already in the bin by adjusting the bin spinning speed. However, the bin's continuous spinning and intermittent lowering movement would be of safety concern if adopted for infield use. The grabber bin filler (fig. 7) could accommodate a range of fruit sizes, due to the adjustable padding thickness, relative distance between the two plates, and reciprocating stroke length. However, the fruit's go-and-stop movement controlled by the two vertical plates reduces and constrains the system's throughput. The distribution pan design (Berlage, 1981) is simple and compact, and would work satisfactorily at low throughput (i.e., 1~2 fruit/s). For higher throughput, the pan needs to spin more quickly, which would cut or even bounce apples, thus resulting in potential bruising. For the bin filler developed by Peterson and Wolford (2002, 2003b) (fig. 8), apples arrive in uniform patterns because of the rotating cylinder brush, but this design also uses a bin spinning approach to achieve uniform fruit distributions, which is not desirable because of safety concerns. Furthermore, the bin movement (in linear direction or spinning) draws energy from the self-propelled platform, making the system more costly (i.e., more engine power and higher fuel cost). The absorbing grate (Kliethermes et al., 2010) and pneumatic self-adjusting bin fillers (fig. 9), though interesting in concept, have not proven to work satisfactorily under actual working conditions. The cone-shaped (fig. 10) and cylinder brush bin fillers work well only at low throughput (i.e., <1.6 fruit/s). Additionally, human assistance is required for lifting the bin fillers. The bin filler developed by our group (fig. 11) has shown satisfactory performance at high throughput (6 apples/s); it is relatively compact and simple, and also requires no manual bin movement. However, fruit need be singulated before arriving at the bin filler in order to avoid apple-to-apple collisions.

BIN FILLERS FOR POSTHARVEST HANDLING

Automated fruit packing lines deliver fruit from conveyor belts to bulk bins via a bin filler (Peterson et al., 2010). Although the basic requirements for infield and postharvest bin fillers are similar, there are fewer design restrictions for postharvest bin fillers. This may partly explain why so many types of postharvest bin fillers have been developed over the

past decades and currently are being used commercially. A harvest platform can accommodate 4 to 6 pickers, and the bin filler thus needs to handle fruit at a throughput of 4 to 6 apples/s, as professional workers can pick at a speed up to 1 apple s⁻¹ person⁻¹ when working on the platform (Mizushima and Lu, 2011; Zhang, 2015). However, postharvest bin fillers usually need to operate at a higher throughput (e.g., filling 10 bins per hour or approximately 7-8 apples/s). Compared to infield bin fillers mounted on the harvest platforms with limited room, space or the size of the bin filler is not a major consideration for postharvest use. Adoption of the mode of bin movement (e.g., spinning or reciprocating) would also be of less concern for postharvest bin fillers, as they normally work in a stationary condition. Among many types of postharvest bin fillers, the simplest filling method is to tilt the bin towards the end of conveyors so as to shorten dropping distance. Pivotal flat conveyor belts, bucket conveyor and hinged panel trays are also used for delivering fruit into the bin. Vacuum cups and inflatable fingers provide additional methods for transporting and distributing fruit in the bin. The following sections give a review of these postharvest bin fillers, which are divided into four categories: (1) tilted bin filling, (2) movable/pivotable bin filler with fixed bin, (3) movable/pivotable bin filler with spinning or reciprocating bin, and (4) vacuum suction and inflatable finger bin fillers.

TILTED BIN FILLING

Tilted bin filling uses a spring or an actuator to incline the container at the initial filling stage, through which the fruit dropping distance is shortened significantly, thus reducing potential bruising damage to fruit during bin filling. As the bin is being filled with more fruit, it is pivoted back gradually by fruit' and its own weight until returning to the original (vertical) position.

Prototype

Carlsen and Baum (1959), Rouse and Wales (1966), McClusky (1968), and Morris (1986) each invented a bin filling system using a similar tilted bin concept. A spring biases the bin to its inclined position at the beginning of filling (left sketch in fig. 12). With more fruit being filled in the bin, their weight gradually overcomes the spring biasing force, causing the bin to automatically return to its normal, upward position. By taking advantages of spring biasing force and fruit mass to control the bin movement, the bin filler design is greatly simplified. Watts and Wright (1975) modified this

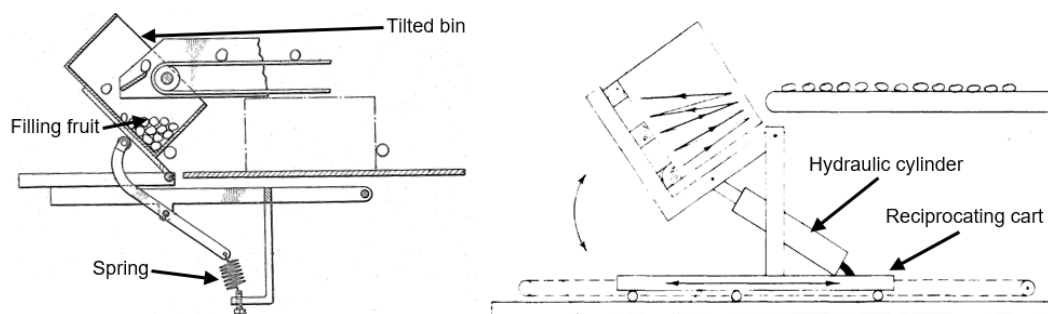


Figure 12. Bin filling systems using a spring (left) and a hydraulic cylinder (right) to tilt the bin (McClusky, 1968; Watts and Wright, 1975).

design by replacing the spring with a hydraulic cylinder (right sketch in fig. 12), which improves the bin's performance. Moreover, the cart in the new design not only supports the cylinder as a base, but also reciprocates the filler and bin horizontally relative to the stationary conveyor, which not only improves fruit distributions in the bin, but also reduces apple-to-apple collisions or collision times because the fruit do not need to roll a long distance to its final place in the bin.

Advantages and Limitations

The tilted bin filling system is simple, as it only consists of a spring or a hydraulic cylinder to tilt the bin at the beginning, and the bin is pivoted back to the normal position automatically with increasing fruit weight. One major concern for this type of bin filler is fruit bruising, because it is unreliable or difficult to control or maintain constant fruit dropping distances throughout the entire filling process, based on the total weight of fruit alone. Accurate control of dropping distances is critical to minimize fruit bruising, considering the fact that the bruising thresholds (i.e., the minimum drop height at which bruising begins to occur) for hard surfaces (e.g., wood) and between apples are only 10 mm and 20 mm, respectively (O'Brien et al., 1980; Hyde, 1997). Moreover, the method is not likely to distribute fruit evenly in the bin, which would otherwise be unacceptable.

MOVABLE/PIVOTABLE BIN FILLERS WITH FIXED BIN

In the concept of movable/pivotable bin fillers with fixed bin, the bin filler is lowered or pivoted downward into a fixed bin to discharge apples. With more apples in the bin, the bin filler moves and/or pivots upward gradually until the bin is fully filled.

Prototype

Griffith (1959) developed a bucket conveyor filling system to fill apples individually into the bin (fig. 13). A conventional conveyor singulates fruit during transportation

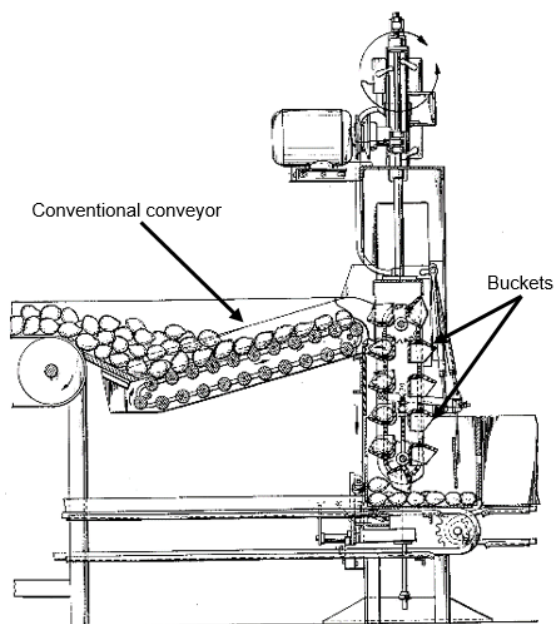


Figure 13. Bucket conveyor filling system (Griffith, 1959).

before they arrive at the bucket conveyor. Singulated fruit are then delivered to buckets, with one bucket accommodating one fruit. The bucket holds and delivers fruit to the bin, during which fruit-to-fruit collisions are avoided. This design requires the bucket conveyor to be synchronized with the conventional conveyor to ensure one bucket for one apple. As fruit are filling the bin, the bucket conveyor system will be lifted automatically and gradually until the bin is full.

Carlsen et al. (1961) developed a filler consisting of multiple disks and cones to lower fruit into the bin in small steps. At the outset of filling, the filler is lowered into the bin, with its bottom being close to the bin floor. Apples, conveyed into the filler through a chute, fall a minimal distance onto the top disk, after which they move through a series of disks and cones with multiple small-distance drops before arriving at the bin. This bin filler was demonstrated to prevent bruising due to small dropping distances. Using the same concept of dividing one single large-distance drop into multiple small-distance drops, Boyd (1994) developed a fruit contact unit filler. Fruit first drop onto the contact unit and then onto the bin, during which the collision magnitude is vastly decreased.

O'Brien (1963) and Hostetler (1966) used a pivotable head to fill fruit into a bin. The bin filling chute, shown in solid and phantom lines, respectively, in figure 14, represents the beginning and end of filling. The filling chute is positioned close to the bin floor at the beginning and pivoted upward while the filling going on to keep a small and constant distance for apple dropping. Accumulated fruit push a lever upward, triggering an electric switch to automatically pivot the bin filler upward.

An automatic filler was developed by Jespersen and Jespersen (1989, 1990), which includes a conveyor belt, a roll of plastic sheet, and a cradle (fig. 15). After exiting the conveyor belt, fruit arrive at the plastic sheet, which performs as a cushioning medium. With more fruit accumulated at the sheet, the cradle lowers down and simultaneously rotates outward to accommodate more fruit. Accumulated fruit at the conveyor belt activates a micro-switch to automatically trigger the cradle lifting.

A bin filling conveyor, consisting of multiple flaps, was developed by Main (1996, 1998) (fig. 16). The filling conveyor is pivotable between the bottom and the top of the bin. Since the flap tail is resilient and the supporting surface ends at the discharging end, fruit carried by the flap would fall off

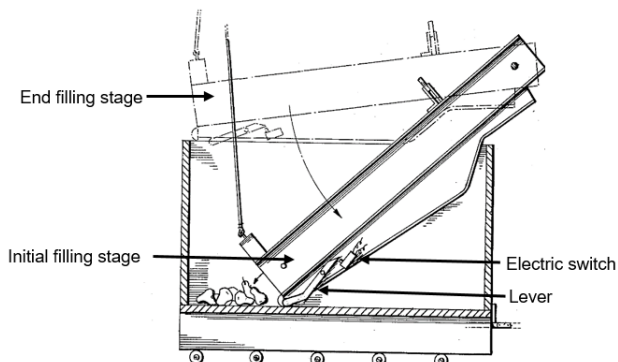


Figure 14. Pivotable head bulk bin filler (O'Brien, 1963).

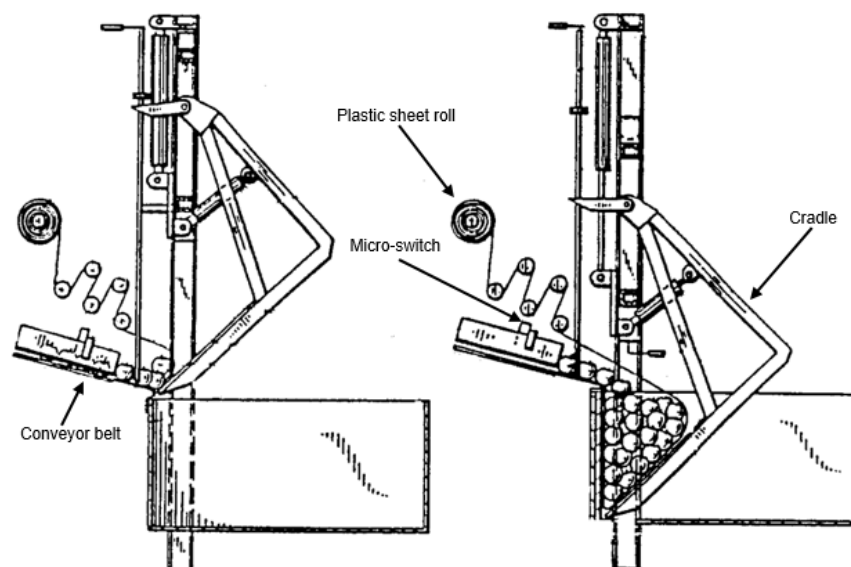


Figure 15. Fruit bin filler consisting of plastic sheet and cradle in two operation positions: bin filling to start (left) and bin filling in process (right) (Jespersion and Jespersen, 1990).

the holding flap tail at the discharging end due to gravity. The phantom line in figure 16 shows fruit falling off the flap and then being caught by another flap, which performs as a cushion to avoid bruising. Furthermore, the catching flap carries later arrived fruit near those already in the bin, preventing fruit from accumulation at the dropping area and, meanwhile, assisting with uniform fruit distributions. The conveyor will be lifted automatically with more apples filled in the bin, which is controlled by a sensor (not shown in fig. 16).

Hanks (2006) developed a system to fill delicate fruit into a bin, which includes an organizer and a delivery head consisting of wave belts (fig. 17). The organizer formats the fruit to a succession of rows, and then the delivery head, consisting of a pair of opposing wave belts, holds them gently to the bin. After being discharged at the end of the delivery head, a drape disperses fruit into the bin. As the filling process is going on, an actuator automatically pivots the delivery head upward to keep it at a suitable position relative to the fruit level in the bin.

To realize uniform fruit distributions and more than 95% of the handled apples graded Extra Fancy, Peterson et al. (2010, 2011) developed a single layer bin filler using a tray to fill apples into the bin (fig. 18). When the hinged tray is

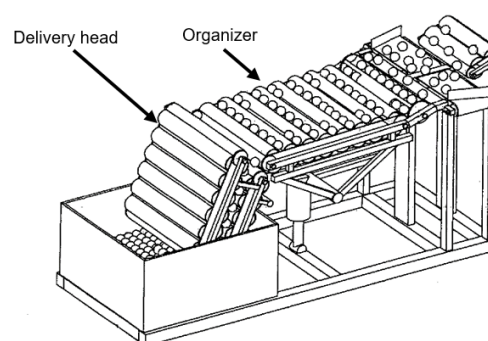


Figure 17. Bin filler with wave belts (Hanks, 2006).

closed, fruit are loaded onto the tray from a conveyor, which is then lowered into the bin. When the tray reaches a specific level in the bin (detected by sensors in real time), a linear actuator is triggered to open the hinged tray for discharging the apples to the bin. Then, the hinged tray is lifted, closed, and moved back to the conveyor for another filling cycle. Since the whole tray is only slightly smaller than the bin and filling is done one layer at a time until the bin is full, uniform distributions of fruit are maintained throughout the entire filling process. Tests on different apple cultivars (i.e., 'Pink

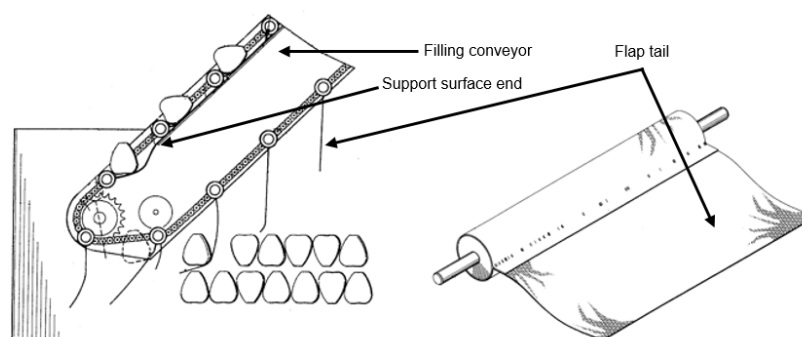


Figure 16. Bulk bin filler: filling head consisting of a series of flaps (left) and a single flap in detail (right) (Main, 1996, 1998).

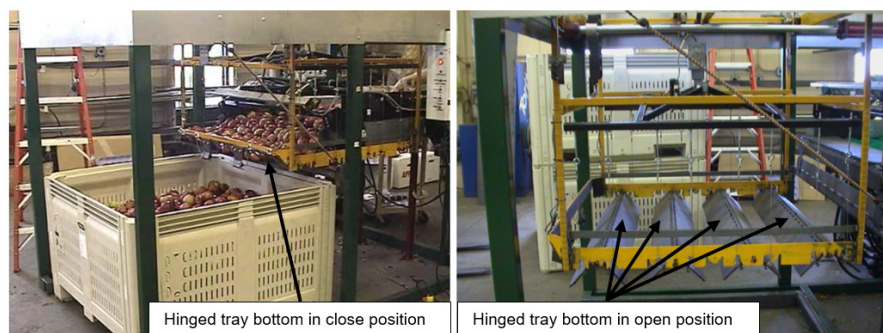


Figure 18. Overview of the single layer bin filler with hinged tray bottom in close position (left) and open position (right) (Peterson et al., 2010, 2011).

Lady', 'Golden Delicious', 'McIntosh', 'Mutsu', 'Delicious', and 'Fuji') showed that more than 97% of apples were graded Extra Fancy.

The bin filler manufactured by Phil Brown Welding, Inc. (Conklin, Mich.) is currently available on the marketplace to fill fruit into a bin (fig. 19). The horizontal belt first transports fruit to the endless fingered belt, which holds and then lowers the fruit down into the bin. A spinning cylinder brush mounted at the end of the fingered belt catches and then distributes fruit in the bin by pushing them away from the dropping area. With more fruit accumulated in the bin, a hydraulic system automatically pivots the filler upward.

The Burg bin filler (Burg Machinefabriek, Kruiningen, The Netherlands) has been adopted in the fruit industry to fill delicate fruit into bulk bins (fig. 20). After being discharged from the fingered belt, fruit arrive at a horizontal cylinder brush for deceleration before reaching the pinwheel. Compared to the pinwheel consisting of four flexible pads (fig. 1), the Burg bin filler has two, but very long discharging pads. A vertical brush further decreases apples' speed before they hit each other. This bin filler could fill up to 8-10 bins per hour. Bin fillers similar to Burg's design but with different conveyor belt configurations are also available commercially (Sorter Spółka Jawna Konrad Grzeszczyk Michał Ziomek, Random, Poland; Durand-Wayland, Inc., La-Grange, Ga.; Van Doren Sales, Inc., Yakima, Wash.).

Advantages and Limitations

The bucket conveyor (fig. 13) transports fruit in a singulated format to minimize or avoid the contacts and collisions between apples prior to being placed in the bin. However, when the system works at high throughput, the fruit would

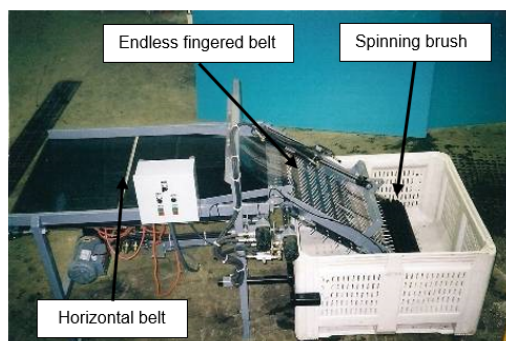


Figure 19. Bin filler with a spinning brush assisting with even fruit distributions (Phil Brown, 2016).

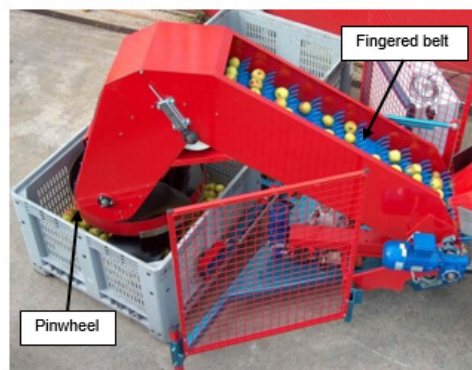


Figure 20. Burg bin filler made by Burg Machinefabriek (Kruiningen, The Netherlands).

exit the accommodating buckets with a high speed, potentially causing bruise damage. The multiple disk-and-cone design (Carlsen et al., 1961) divides a long-distance drop into multiple small-distance drops, which significantly lowers collision magnitudes. However, the system is bulky and complex, and thus may not be reliable for long-term use. Additionally, system throughput is a potential issue. Although the chute (fig. 14) and contact unit (Boyd, 1994) are both simple in design, their performance in terms of fruit distributions and bruising is still a major concern in practical use. While it seems a good idea to use a cradle and a plastic sheet to handle fruit (fig. 15), bruising is again a concern, because the later arrived apples would collide with earlier arrived ones many times before arriving at their final places. Although the system with multiple flaps (fig. 16) simplifies the filling processes involving delivering, cushioning, and distributing apples, its flaps would not be able to handle apples gently when working at high throughput, which is also likely true for the wave belt filler (fig. 17). While the hinged tray bin filler (fig. 18) helps achieve uniform fruit distributions, it does not fill the bin continuously, thus limiting its application, as many postharvest handling operations require the bin filler to work continuously. The bin filler shown in figure 19 works well for non-delicate fruit (e.g., oranges), but it is not suitable for delicate fruit (e.g., apples). Other commercial bin fillers (e.g., the Burg bin filler in fig. 20) have good system throughput with satisfactory performance, but they are overall bulky and complex.

MOVABLE/PIVOTABLE BIN FILLERS WITH SPINNING OR RECIPROCATING BIN

Compared with the designs described in the previous section, in which bins are all fixed, the bin fillers presented in this section require moveable bins (e.g., spinning or reciprocating). This design is primarily intended to reduce bruising and achieve more uniform fruit distributions.

Prototype

Huntoon (1964) described a system for placing fruit into a bin or large container gently and automatically, which mainly consists of a pivotable filler, a spinning bin, an actuator, and a sensing plate. At the outset of filling, the pivotable bin filler head is inserted into the bin, close to the bin floor (bottom phantom lines in fig. 21). As the bin is being filled with more fruit, the filler head pivots upward automatically until the bin is full (top phantom lines in fig. 21). The bin spins to prevent fruit from mounding in the center. If too many early arrived apples mound at a certain area in the bin, the latter apples are likely to roll down from the apple pile peak to a dent, which may cause bruising. When the sensing plate is pushed by an increased apple level in the bin, an actuator is activated to push the bin filler upward. Powell (1978) updated this invention: (1) being portable; (2) eliminating bin spinning; and (3) feeding head oscillation to assist with uniform fruit distributions. The portable feature makes it convenient to be used as an independent unit at any needed locations.

Muller and Muller Jr. (1985) made two further modifications to the Huntoon's (1964) system. First, an infrared sensor is used to collect the apple-in-the-bin level information for more reliable lifting of the bin filler. Second, adding swingable dividers helps absorb the kinetic energy of fruit dropping from a conveyor to the pocket, thus preventing fruit from bruising (fig. 22). After apples drop into the pocket, the inclined cam track guides the dividers perpendicular to the track for fruit transportation. When fruit arrive at the discharge end, the deformable pocket performs as a cushioning medium to decrease the apples' exiting speed.

A conveyor consisting of a series of brushes in a row format was developed by Myers and Sheetz (1980) to transfer delicate fruit from conveyors to a bulk bin (fig. 23). Beyond holding fruit firmly during transportation, the brushes also separate apples to reduce or even eliminate apple-to-apple collisions. A resilient cushion panel, mounted beneath the

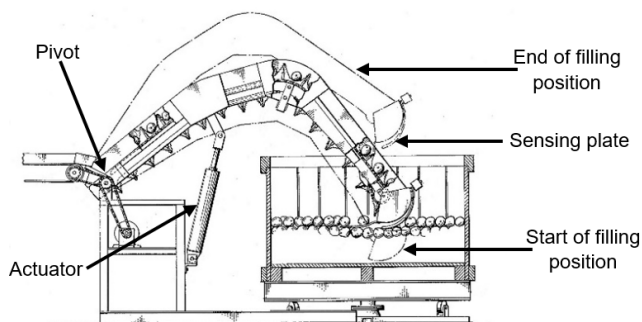


Figure 21. Fruit depositing system with a pivotable bin filler and a spinning bin (Huntoon, 1964).

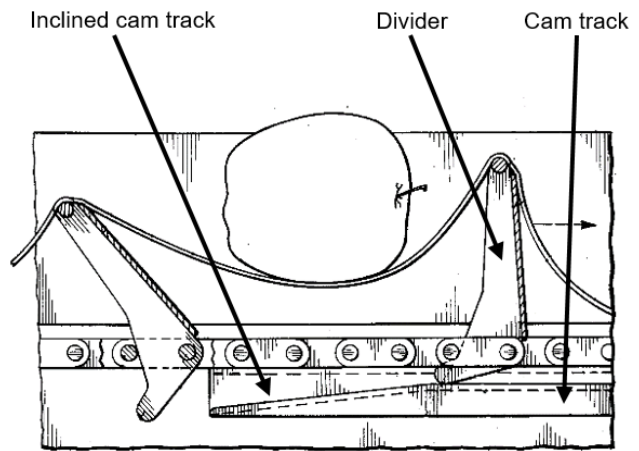


Figure 22. Swingable pocket divider (Muller and Muller Jr., 1985).

two vertical parallel conveyors, catches apples while decelerates their speed. Drapes, with one end attached to the cushion panel, further reduce collision magnitudes between apples. During filling, the bin filler and bin keeps moving in vertical and horizontal directions, respectively, in order to achieve uniform distributions.

Main and Main (1996, 1997) developed a bin filling apparatus, consisting of a transfer belt, a distribution belt, and a power unit to rotate, lift and lower the bin. The power unit first rotates the bin 90° and then lifts it to start filling (phantom lines in fig. 24). Fruit from the transfer belt first fill the distribution belt, which then enters the bin horizontally. Once reaching the bottom of the bin, the distribution belt starts to retract from the bin and also rotate at the same time, so that all fruit on the belt will be discharged with small

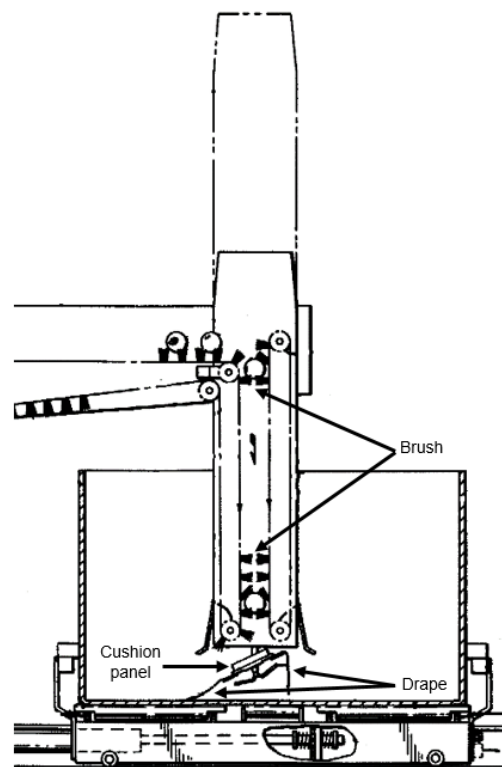


Figure 23. Brush conveyor bin filler (Myers and Sheetz, 1980).

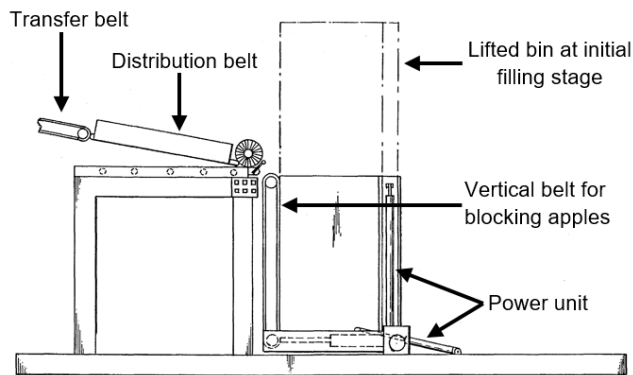


Figure 24. Fruit bin filling apparatus with a reciprocating distribution belt to deliver fruit into the bin (Main and Main, 1997).

dropping distances. After one layer of fruit is filled, the bin is automatically lowered by a pre-determined distance (usually the height of an apple) for the next filling cycle. Apples in the bin are blocked by a vertical belt from rolling out.

Advantages and Limitations

By transporting and discharging fruit in a row-by-row format, the bin fillers presented in figures 21 and 23 can effectively reduce apple-to-apple collisions, but also limit the system's throughput. To increase the system's throughput, the conveyor needs to run at a high speed, which would result in more bruising to the apples. The bin filler shown in figure 24 fills bins layer by layer, thus reducing potential bruising to fruit, but the system can only run intermittently due to the reciprocating movement of the distribution belt, which would result in low throughput and is also unacceptable for many postharvest handling operations.

VACUUM SUCTION AND INFLATABLE FINGER BIN FILLERS

Beyond the methods mentioned above for fruit transport (e.g., conveyor, tray, and tube), vacuum suction is another approach to hold and then deliver fruit from a conveyor to a bin. Furthermore, a series of inflatable fingers could be used to fill fruit into a bin, taking the advantage of variable relative distances between fingers due to their alternative inflation and deflation to hold and release fruit.

PROTOTYPE

A few versions of bin fillers were developed for delivering fruit of random sizes and shapes to bins, using a vacuum suction transfer head (fig. 25) (Gee and Charles, 1965; Gee and Seagraves, 1965; Voullaire, 1965, 1967; Zwiacher et al., 1965; Paddock, 1971; Stilwell and Westerling, 1981). After fruit arriving at a conveyor in a randomly-oriented, closely-packed, and single-layered array, the transfer head, consisting of multiple pivotable vacuum gripping cups spaced substantially less than the fruit diameter, moves immediately above the fruit and then holds and conveys them to the bin. When the transfer head reaches an appropriate position in the bin (determined by sensors), the cups release the fruit. The filling process is repeated until the bin is fully filled.

Frost (1966) described a pickup head mounted with a series of inflatable fingers to fill fruit into bins (fig. 26). With

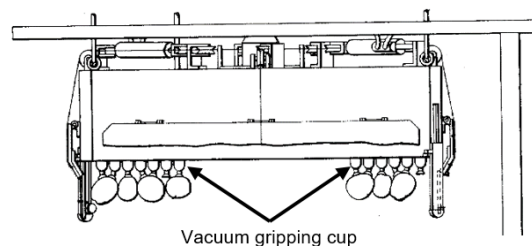


Figure 25. Vacuum transfer head (Stilwell and Westerling, 1981).

both adjustable finger arrangement and profile, the filler can be used to fill fruit of different sizes (e.g., apples and cantaloupes) into bins. To effectively use the filler, fruit need to be first arranged in a certain format. The filler's head is then lowered with deflated fingers, which are inserted into the gaps between fruit; thereafter, the fingers are inflated to hold the fruit. The head is then lifted by a hydraulic system, rotated 90°, and lowered down to an appropriate level in the bin. Finally, the fingers are deflated to release the fruit.

Advantages and Limitations

Both fillers of the vacuum suction and inflatable finger system have advantages of filling fruit evenly in a bin without causing bruising damage, and they are being increasingly used in many packinghouses for filling small cartons that are ready for shipping to the market. Both fillers work best when the fruit are of uniform size or after fruit have been sorted by size. However, the systems' relatively low throughput would make it unsuitable for filling bins or other large containers. Additionally, the system's overall complexity in design increases the chance of malfunctioning for long-term use, which would increase maintenance cost and downtime.

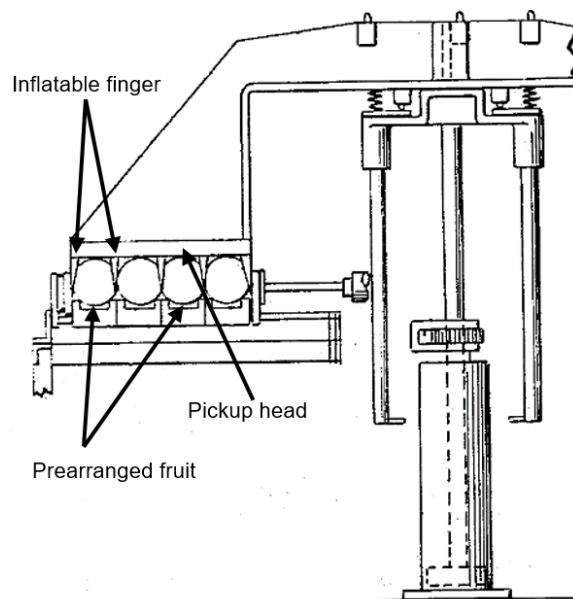


Figure 26. Bin filling and packing apparatus with a pickup head installed with inflatable fingers (Frost, 1966).

AUTOMATIC CONTROLS DURING FILLING

The majority of bin fillers reviewed in this article would be lifted up automatically during the filling, with minimum or no human's involvement. Regardless of infield or post-harvest use, their control systems need to measure and/or monitor the distance between the filler and fruit level in the bin in order to maintain an appropriate distance. As more fruit are filling the bin, the distance between the apple level and bin filler is decreased. If the bin filler is lifted too late, apples would be congested at the filler; and if lifted too early, a large dropping distance between the filler and apple level would cause bruising to fruit. It is therefore crucial that the control system is able to lift the bin filler at the right time.

Overall, the control systems can be divided into two categories: mechanical and optical sensor-based. The mechanical control system is usually based on limit switch, which enables a motor (hydraulic or electric) to lift, or stop lifting, the bin filler. The mechanical system performs as a medium between apples and the limit switch. With the filling process going on, the mechanical system would be pushed up by apples, and it in turn pushes the limit switch arm to actuate the motor, which lifts the bin filler until the limit switch arm is no longer being pushed. The other system is based on proximity sensors mounted at the bin filler frame, which could collect apple level information in real time. An on-board microcontroller processes the data and then makes a decision on whether to lift the bin filler or not.

MECHANICAL SYSTEM-BASED CONTROL

Early versions of the mechanical system-based control use a boot switch or limit switch to detect apple height in the bin (e.g., switches shown in figs. 4 and 14). Since fruit are

often not uniformly distributed in the bin, which could result in unstable or inconsistent contacts between the switch and apples in the bin, it is therefore difficult for the bin filler to lift at the right time. In the updated mechanical control systems, a floating panel is often used. In addition to sensing the apple level in the bin, the floating panel could also assist with uniform fruit distributions. When the distance between the filler and apple level is large (left sketch in fig. 27), the floating panel is not in contact with the apples and hence lifting is not needed (position 1 in fig. 27). On the other hand, as the distance decreases, the floating panel is pushed upward by the increased apple level (position 2 in fig. 27), which then pushes the limit switch to lift the bin filler. The mechanical system-based control has been used in many commercial bin fillers, such as Pluk-O-Trak (fig. 2) and Revo (fig. 3), in which the bin spins during filling.

SENSOR-BASED CONTROL

The sensor-based bin filler control uses an IR sensor coupled with an on-board microcontroller, to detect the apple level in the bin. The IR sensor is usually used with a pinwheel, to which flexible pads are attached. The pads would not be pushed upward when the apple level in the bin is low (a large distance between the pinwheel and apple level in bin as shown in the left sketch of fig. 28). As the bin is filled with more apples, the pads are pushed upward by apples and the detected distance (distance 2 in the right sketch of fig. 28) becomes smaller. By analyzing the data received from the IR, accurate estimation of the apple level in the bin can be made to determine if the bin filler needs be lifted. This sensor-based automatic control has been adopted for a number of bin fillers, such as in DBR harvester (fig. 1) and the Pennsylvania State University harvest-assist unit (fig. 10). In

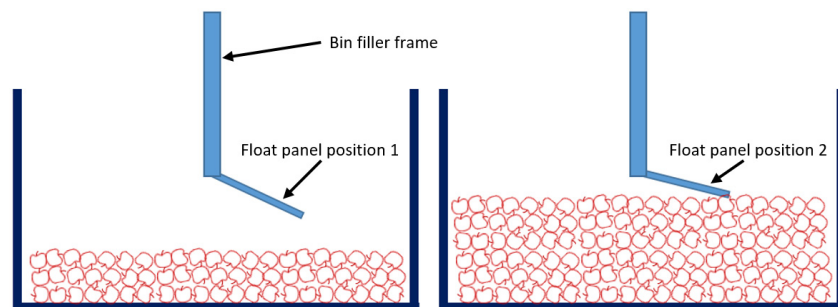


Figure 27. Mechanical system-based automatic bin filler control: left, float panel is not in contact with fruit, and lifting is not needed; right, float panel is in contact with fruit, and lifting is needed (bin spins during filling).

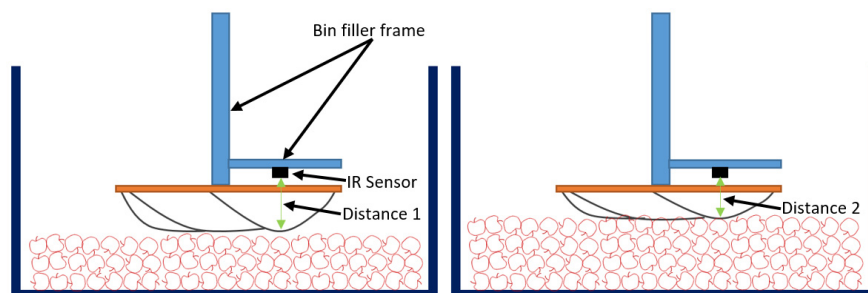


Figure 28. Sensor-based automatic bin filler control: left, pinwheel pads fully above apple level, and lifting is not needed; right, pinwheel pads are pushed upward by apples, and lifting is needed (pinwheel spins during filling).

addition to the IR sensor, a Hall Effect sensor is also used to monitor the pinwheel's spinning speed to obtain more accurate information about apple-in-the-bin level for the bin filler incorporated into the USDA apple harvest and infield sorting platform (fig. 11). In some other bin fillers, such as tray (fig. 18) and vacuum transfer head (fig. 25), multiple proximity sensors are used to determine when to release fruit into the bin.

ADVANTAGES AND LIMITATIONS

Although the mechanical system-based control is simple in design, its performance is mainly determined by fruit distributions in the bin. If more fruit are distributed around the center, the bin filler is likely to be lifted earlier, resulting in a large distance gap between falling apples and apples already in the bin. As the bruising threshold (i.e., the maximum dropping height at which bruising begins to occur on apples) between apples is only 20 mm (O'Brien et al., 1980; Hyde, 1997), early lifting of bin filler is more likely to cause apple bruising. While the sensor-based control could collect accurate data on the relative distance (distances 1 and 2 shown in fig. 28) and thus better control the lifting of the bin filler, its performance is also dependent on apple distributions. As the pinwheel spins, the sensor mounted on the frame can only measure the relative distance between the sensor and the area directly below the sensor. If the detected area is lower or higher than the overall apple level in the bin, the bin filler's performance could be negatively affected. Hence, regardless of which control system (i.e., mechanical or sensor-based) is used, it is important that the bin filler enables distributing apples uniformly in the bin.

DISCUSSION

More than 50 types of bin fillers from various sources, including patent documents, research publications, and commercial products, have been reviewed in this article. While a few bin fillers have been successfully incorporated into harvest platforms and used in warehouses to handle fruit, most of them were never adopted commercially. Many of these bin fillers are still short of meeting the requirements in performance, throughput, cost, and design (i.e., size and simplicity). Due to potential excessive bruising damage to delicate fruit, the designs of tilted bins and movable or pivotable bin fillers (Carlsen and Baum, 1959; McClusky, 1968; Boyd, 1994) would not be suitable for commercial adoption. Although space is not critical for postharvest handling, it is a major consideration in determining whether a bin filler design is suitable for use with harvest platforms. Many bin fillers (Carlsen et al., 1961; Huntoon, 1964; Jespersen and Jespersen, 1990) are still too bulky to be adaptable for infield use. Infield and postharvest bin fillers need the throughputs of 4-6 apples/s and 8-10 apples/s, respectively, and many of the bin fillers reviewed in this article (Berlage, 1981; Peterson et al., 2010; Zhang et al., 2014, 2016a) do not meet these throughput requirements, and thus could be problematic when adopted for harvest platforms or packing lines. Regardless of being used infield or in warehouse, the bin filler needs be simple and reliable in performance. Bin fillers, such

as those developed by Gee and Charles (1965), Voullaire (1965, 1967), and Frost (1966), do not meet this criterion. Uniform fruit distribution is a major consideration in the design of a bin filler, so that each bin would be filled to its full holding capability, thus lowering cost for growers and packers, and more importantly, this would help reduce fruit bruising due to less apple collisions in the bin and better, more accurate control of the lifting of the bin filler during filling. The bin fillers developed by Kliethermes et al. (2010) and O'Brien (1967, 1969), are likely to have non-uniform distribution issues, and thus may not be suitable for practical adoption. To improve fruit distributions, it is common to use the design of bin movement (i.e., reciprocating, spinning, or tilting) in commercial bin fillers and experimental prototypes (Rehkugler et al., 1976; Peterson and Wolford, 2002; Van Wijngaarden and Weterings, 2004; Munckhof, 2016). This design approach is, however, not desirable for infield use because it could pose safety hazards to workers and also would need extra space to accommodate the bin movement. The foam roller bin filler (fig. 11) developed by our group is simple, compact and easy to adapt for infield use. The current version requires apples to be singulated before entering the bin filler. However, fruit pre-singulation may not be necessary if two or more sets of foam rollers, instead of one as used in the current version, are adopted, coupled with an appropriate foam roller spinning speed.

CONCLUSION

Over the past 60 years, a large variety of bin fillers have been developed for infield use and postharvest handling. While bin fillers are widely used for postharvest handling, they are still not popular for infield use, mainly out of cost and technical or performance concerns. With the increasing use of harvest platforms in recent years, the demand for new, cost-effective, compact, and fully automated infield bin fillers is on the rise. Most bin fillers are large in size and expensive due to the methods used to transport fruit (e.g., fingered conveyor, chute, and bucket conveyor) and the needs of having automatic lifting and control functions to prevent fruit bruising. For most experimental and commercial bin fillers, uniform fruit distributions during filling are accomplished by either using the bin movement (including tilting) approach or the bin filler movement method. Since bin movement would pose safety concerns for infield use, the bin filler movement approach is a more suitable choice. The pinwheel design with soft pads would achieve good performance in fruit distributions, if apples can be guided to different directions when exiting the pads, thus spreading more evenly instead of being limited to small local areas. This design, coupled with the foam roller, looks particularly promising for infield use, as it simplifies the overall design and makes the system more compact and thus easy to fit into different harvest platforms.

Automatic lifting of the bin filler during fruit filling is usually accomplished by using either mechanical devices or optical sensors coupled with microcontroller. However, human assistance is still required when lowering the bin filler into the bin at the beginning of filling or when the bin is full

and needs to be replaced, during which the filling operation and/or harvest activities (in the case of infield use) have to be suspended temporarily. Hence, new generation bin filling technology with full automation or even artificial intelligence is needed, so that it requires no or little human assistance during the filling and handling of bins, while without temporarily suspending filling operations and/or harvest activities.

ACKNOWLEDGEMENT

This research was supported by funding from the Michigan Apple Committee.

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