Innovative Technology for Apple Harvest and In-field Sorting

Renfu Lu, Zhao Zhang and Anand K. Pothula
USDA/ARS, 524 S. Shaw Lane, Room 224, Michigan State University, East Lansing, MI 48824
[Renfu.lu@ars.usda.gov]

Currently, many orchard operations, including thinning, pruning, and harvesting, still rely on manual labor. Harvesting, in particular, is labor intensive, and it accounts for approximately 15% of total production cost (Gallardo et al. 2010; Gallardo and Galinato 2012). Harvest efficiency enhancement is therefore of great concern to apple growers. In recent years, more and more low-density, unstructured orchards have been transformed into high-density, structured orchard systems, which create a more favorable condition for orchard mechanization and automation (Xu 2016). Consequently, the traditional harvest method of using ladders and picking bags has been gradually replaced by harvest assist platforms. Currently, there are many types of commercial harvest platforms, both domestic and foreign, on the market; they vary in design, performance and price (Figure 1).

> **"Our laboratory has engaged in the development of apple harvest and automated in-field sorting technology for the past few years. Our goal for the research is to develop cost-effective technology to help growers reduce harvest/labor costs and achieve postharvest storage/packing savings."**

Several recent studies (Baugher et al. 2009; Robinson and Sazo 2013; Robinson et al. 2013; Zhang et al. 2016a,b) reported that the use of harvest platforms could increase labor efficiency by 15% to 60%. These gains, however, are still far from reaching the maximum potential of 80% to 100%, due to technological deficiencies with the existing commercial harvest platforms, which include, but are not limited to, the need for a worker to operate the platform, use of picking bags, and frequent downtimes for

Figure 1. Commercial self-propelled apple harvest assist platforms: A. Flow Thru Harvester, Precise Manufacturing, Inc. (Photo courtesy Precise Manufacturing, Casnovia, MI);); B. Huron Fruit Systems, Wafler Farms (Wolcott, NY). C. DBR Vacuum Harvester, Phil Brown Welding Corp. (Conklin, MI): D. Pluk-O-Trak Apple Harvester, Munckhof (The Netherlands). (Disclaimer: Mention of commercial products is only for providing factual information for the reader, and does not imply endorsement of the products by USDA over those not mentioned.)

handling empty and full bins. Moreover, the current harvest platforms do not have the capability of recording and optimizing the performance of individual workers, which could, in turn, negatively affect the overall harvest efficiency of the crew, which is typically four to six workers. Hence, there is considerable room for technological innovations to the existing harvest platforms.

Benefits From In-field Sorting

Conventionally, all harvested fruit, regardless of their quality grades, are placed in the same bins and then hauled to a shed for storage. Postharvest storage and packing can account for one third or more of the total production cost (Wunderlich et al. 2007). Moreover, mixing good fruit with inferior or defective fruit would make the entire lot more susceptible to disease or pest invasion during postharvest storage, which could result in devastating loss to growers, if intensive pest/disease management measures were not taken. Therefore, improvement to the current postharvest handling practices represents a great potential for achieving significant cost savings for growers. For example, for a 50-acre orchard with a yield of 50 bins/acre and 10% low-quality fruit that are not suitable for the fresh market, the orchard owner could have gross savings of $34,000 in postharvest storage and packing, if the culls were removed at the time of harvest (the calculation assumes that the costs for postharvest controlled atmosphere storage for fresh apples, cold storage for processing apples, and sorting/grading/packing are $32/bin, $12/bin, and $116/bin, respectively).

In Michigan, New York and Pennsylvania, many orchards grow only processing apples. These orchards usually are not managed as intensively as fresh apple orchards. Since there are large price differentials between processing and fresh apples, in-field sorting could bring additional economic benefits to the growers, because it would allow them to sell a portion of the harvested fruit to the fresh market, which would otherwise go for processing.

Despite potential economic benefits, in-field sorting currently is not practiced by growers and no appropriate technology is available commercially. While automated machine vision-based sorting technology is widely used in the packinghouse, in-field sorting would require a completely different set of technological innovations; it needs to be cost-effective and fully integrated with the harvest platform operating in limited space under rugged orchard conditions. Most commercial horticultural equipment companies, operating as a small business, have limited technical and financial resources, and hence are less inclined or willing to invest in high-cost R&D for technological innovations in harvest and in-field sorting.

In view of the current status in harvest assist and in-field sorting technologies, we recently conducted an economic analysis of the cost benefits of adopting harvest and in-field sorting practices (Mizushima and Lu 2011; Zhang et al. 2016). Our analysis showed that integration of harvest platform and in-field sorting technologies into one machinery system has the potential for achieving greater production and labor savings for growers. Figure 2 shows gross savings (without considering the machinery cost) that would be accrued from harvesting efficiency improvement and in-field sorting, respectively, for the fresh apple grower. The example assumes a 50% harvest efficiency increase from the machine operating 360 hours for the harvest season, with which a crew of six workers would be able to harvest 3,240 bins for the season. Gross savings from using the harvest platform are constant, and determined only by the machine's harvest efficiency improvement. However, savings from in-field sorting depend on the processing apple or cull incidence; the higher the processing apple incidence, the more savings in-field sorting will bring. For example, when the processing apple cull incidence is 15%, gross savings from in-field sorting would be $58,000, compared with $27,000 savings resulting from the harvest efficiency increase.

Figure 3 further shows the net annual benefits that would be accrued from the harvest platform with or without an in-field sorting function, when the machine's price ranged between $60,000 and $160,000 (the machine's annual ownership and operating costs have already been factored in for the calculations). Net annual benefits accrued from the harvest efficiency improvement are limited (<$16,000), even when the machine costs as low as $60,000. Alternatively, the net annual benefits from both harvest efficiency improvement and in-field sorting would range between $58,000 and $74,000, when the machine price ranges from $60,000 to $160,000 and the processing apple cull incidence is 15%. This example clearly demonstrates potential greater economic benefits of using the harvest platform integrated with the in-field sorting function. Our economic analysis (Mizushima

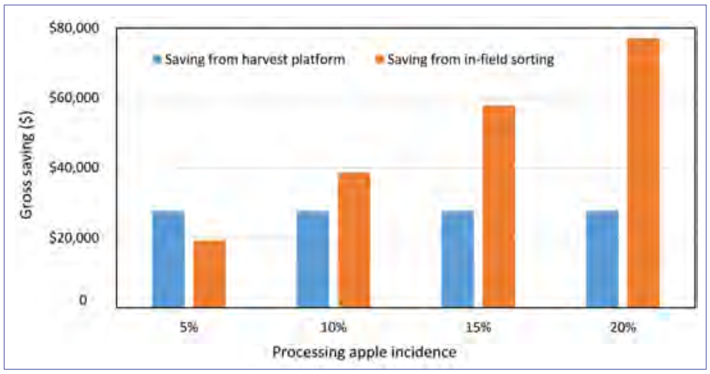

Figure 2. **Gross savings (without considering the machine cost) from harvest efficiency improvement and in-field sorting for the processing apple cull incidence between 5% and 20% (assuming that the machine operates 360 hours/harvest season with 50% harvest efficiency increase and a crew of six workers will be able to pick 3,240 bins for the season).**

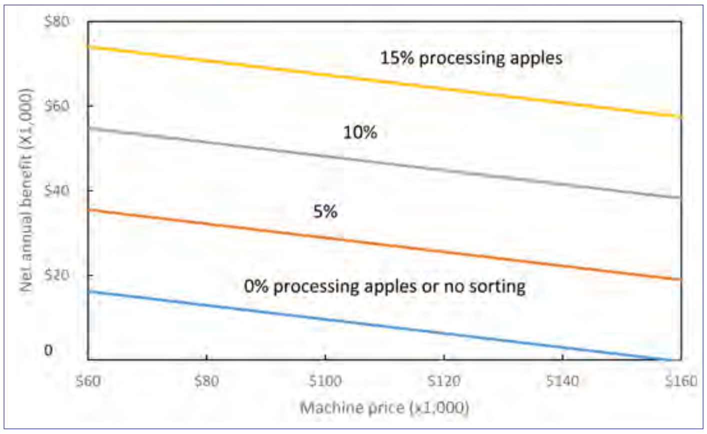

Figure 3. **Net annual benefits (after subtraction of the machine's annual ownership and operating costs) accrued from using the harvest platform with or without in-field sorting function for orchards with 0% (equivalent to no sorting) to 15% processing apple incidences. The machine is assumed to increase the harvest efficiency by 50%, and it operates 360 h/harvest season with a harvest crew of six workers.**

and Lu 2011; Zhang et al. 2016) further showed that processing apple growers can also benefit from the use of the harvest platform integrated with the in-field sorting function.

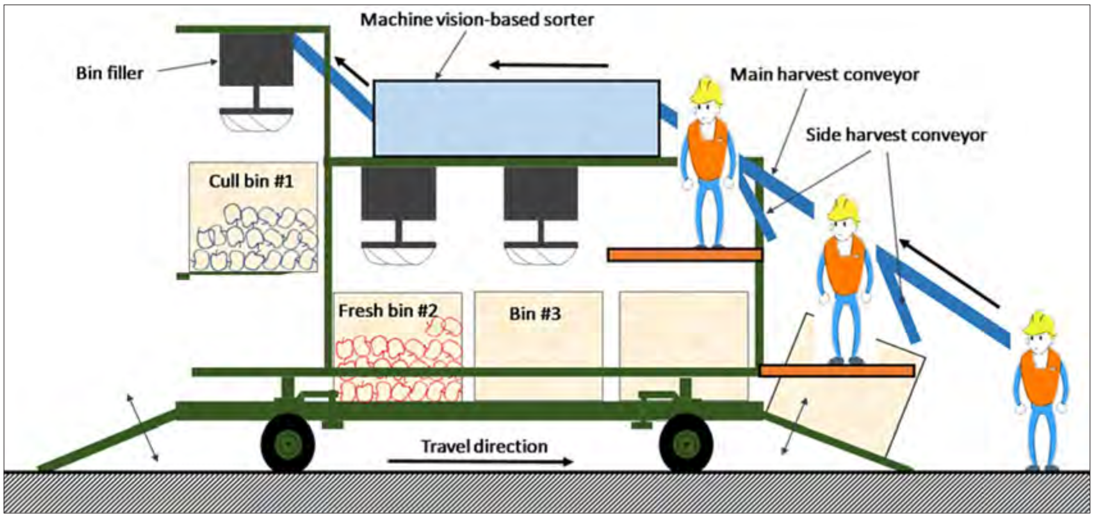

Figure 4 . Schematic of the apple harvest and in-field sorting machine (Pothula et al. 2016)

Self-Propelled Harvest and In-field Sorting Machine

Our laboratory has engaged in the development of apple harvest and automated in-field sorting technology for the past few years. Our goal for the research is to develop cost-effective technology to help growers reduce harvest/labor costs and achieve postharvest storage/packing savings.

In 2016, we designed and constructed the first self-propelled apple harvest and in-field sorting prototype machine, in collaboration with a commercial horticultural equipment manufacturer in Michigan. The new machine (Figures 4 & 5) utilizes low-cost sensors, controls and a computer for productivity improvement and cost savings, and it can accommodate at least six workers. While the prototype still requires a worker to steer the machine in the orchard, auto steering will be considered in the future. Picking bags are replaced with the harvest conveyors, which increase harvest efficiency and also reduce the physical demand for workers. Harvested fruit is transported from three pairs of harvest conveyors to the main conveyor and then to the machine vision inspection chamber (Figure 4). The machine vision system performs the functions of transporting, singulating (i.e., arranging fruit in linear sequence with a space separating each fruit for easy identification and inspection) and rotating fruit, and then imaging and grading. The digital camera takes multiple images of each fruit to cover its entire surface and the in-house developed computer software then performs image processing of the acquired images to determine the quality grade of each fruit, based on its color, size or weight (which is estimated from the fruit's size and shape), and presence or absence of blemishes (currently not yet functional). Next, the graded fruit is sent to the sorter, which directs the fruit to the destination bins. Before running the machine vision system, the user can choose the default fruit grading standards or select their own grading criteria in terms of fruit color and size. The sorting system can sort fruit into two or three quality grades (cull, processing and fresh). However, the current version of the machine only sorts culls or processing apples from fresh market fruit.

Bin filling plays a critical role in placing graded apples in the bin without causing bruising damage to the fruit. Because of limited space available, the bin filler for the harvest platform needs be compact so that it can fit into the machine. After comparing different design ideas, we have come up with a new, simple bin filler design. It allows apples to drop freely from the sorter into the bin filler, which then disperses the apples in the bin gently and evenly. Laboratory tests showed that the new bin filler did not cause bruises to apples, and the bruising damage to some of the test apples occurred mainly when they hit the bottom of the empty bin (improvements to the bin filler are under way to address this issue). There are three bin fillers for the harvest and sorting machine (Figure 4); two are used for handling culls and fresh apples, respectively, and the third is used as a backup bin, when either the cull or fresh fruit bin is full. Each bin filler operates independently and is fully automated through sensors and an on-board microchip.

Figure 5. The apple harvest and in-field sorting prototype machine tested in a commercial orchard in Michigan during the 2016 harvest season.

Another important feature of the machine is automatic bin handling. Once the software is fully implemented later this year, the machine will automatically handle empty and full bins without human involvement. As the machine is traveling in the orchard, it picks up empty bins that have been placed in the orchard and then moves them into proper positions on the platform. When the fresh fruit bin (#2 in Figure 4) is full, the bin filler sends a signal to the computer, which then directs future fresh apples to the backup bin #3 (alternatively, the computer can activate the hydraulic system to unload the fresh bin (#2) in the rear of the machine and then move new empty bins into the positions of bins #2 and #3). Once both fresh bins are full, the computer will activate the hydraulic system to unload the bins to the ground, while at the same time, the new empty bins will be moved into positions to continue the filling operation. Likewise, when the cull bin (#1) is full, the computer will trigger the hydraulic system to lower the bin and then unload it. During the handling of the full cull bin, the incoming new culls will be directed to the backup bin #3 (assuming it has not been used for fresh apples at the time), so the harvest crew can continue picking activities without halting. Once the fresh bin (#2) is full and unloaded, the backup bin (#3) for culls will be moved to the position of cull bin (#1) and new empty bins will be moved into the positions of bins #2 and #3. Through the computer software, we can optimize the handling of individual bins to limit the downtimes for the harvest crew to a minimum.

During the fall of 2016, the new prototype machine was tested twice in a commercial harvest orchard in Sparta, Michigan. While the machine has met our initial goal, we have also identified several areas of improvement. For 2017, we have planned on improving the harvest conveyors and bin fillers for better handling of harvested fruit and also refining the automatic sorting system for a higher sorting capacity. Moreover, we will complete the software for automatic handling of bins and fully implement it with the improved machine. For the coming harvest season, we will test the improved machine in a commercial orchard to evaluate its performance and bruising damage to harvested fruit. We will hold a field demonstration of the machine to seek inputs and comments from growers, extension specialists and others. Our ultimate goal is to establish a partnership with a commercial horticultural equipment manufacturer to transfer the developed technology to the apple industry.

Acknowledgements

The research reported in this article is supported by Michigan Apple Committee. We would like to thank our commercial collaborator, Precise Manufacturing, Inc. in Casnovia, MI, who has worked with us closely in the design and construction of the prototype machine. We thank Schawllier's Country Basket for allowing us to test the prototype machine in their orchard during the 2016 harvest season. Finally, we wish to thank James Engelsma and Chris Kropf, apple growers in Michigan, and Phil Schawllier and Amy-Irish Brown, MSU fruit extension specialists, for their support, advice and many insightful suggestions for the research.

References

Baugher, T., Schupp, J., Lesser, K., Harsh, R. M., Lewis, K., Seavert, C., and Auvil, T. 2009. Mobile platforms increase orchard management efficiency and profitability. Acta Hort., 824: 361–364.

Gallardo, K., and Galinato, P. 2012. 2012 Cost estimates of establishing, producing, and packing Red Delicious apples in Washington. Washington State University.

Gallardo, K., Taylor, M., and Hinman, H. 2010. 2009 Cost estimates of establishing and producing gala apples in Washington. Washington State University.

Mizushima, A. and Lu, R. 2011. Cost benefits analysis of in-field presorting for the apple industry. Appl. Eng. in Agric., 27(1), 33-40.

Pothula, A. K., Zhang, Z., and Lu, R. 2016. Development of a cost effective apple harvest and sorting system. 2016 Great Lakes Expo for Fruit, Vegetable and Farm Market, Grand Rapids, MI, December 6–8, 2016. (Poster)

Robinson, T., Hoying, S., Sazo, M. M., DeMarree, A., and Dominguez, L. 2013. A vision for apple orchard systems of the future. New York Fruit Quarterly, 21(3): 11–16.

Robinson, T., and Sazo, M. M. 2013. Recent advances of mechanization for the tall spindle orchard system in New York State – Part 2. NY Fruit Quarterly, 21(3): 3–7.

Wunderlich, L., Klonsky, K. M., and DeMoura, R. L. 2007. Sample costs to establish and produce apples (Fuji Variety). Cost and return study report AP-IR-07. Davis, Calif.: Agricultural & Resource Economics, University of California. Retrieved from http://cecentralsierra.ucanr.edu/files/60510.pdf.

Xu, K. 2016. Making apple trees friendlier for mechanized harvesting. New York Fruit Quarterly, 24(3): 29–32.

Zhang, Z., Heinemann, P., Liu, J., Baugher, T., and Schupp, J. 2016a. Development of mechanical apple harvesting technology – a review. Trans. ASABE. 59(5): 1165–1180.

Zhang, Z., Heinemann, P., Liu, J. D., Baugher, T., and Schupp, J. 2016b. Design and field test of a low-cost apple harvest-assist unit. Trans. ASABE. 59(5): 1149–1156.

Zhang, Z., Pothula, A. K., and Lu, R. 2016. Economic analysis of a self-propelled apple harvest and infield sorting machine for the apple industry. ASABE Paper No. 162456644. St. Joseph, MI: ASABE.

Renfu Lu is a Research Agricultural Engineer and Research Leader with the USDA/ARS research unit on the campus of Michigan State University, East Lansing, MI, whose research is focused on sensors and automation for quality assessment of fruits and vegetables.