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Harvest Management Information System for Specialty Crops

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Abstract. *Herein we present a Harvest Management Information System (HMIS) that combines a novel real-time Labor Monitoring System (LMS) with a cloud-based harvest management software. The LMS consists of: (i) a digital weighing system; (ii) a radio frequency identification (RFID) reader; (iii) a GPS; and (iv) a computational unit. It reads each picker's ID (RFID bracelet), measures the weight of fruit, and records the time and location of every fruit drop as pickers empty their buckets directly into bins. The collected data can be transmitted wirelessly to the server in real-time. The cloud-based software receives and processes the LMS data on labor activities, visualizes the collected data, and can extract the data necessary for management information and automated filling of documents (e.g. payroll, yield maps). The HMIS can be used as a management tool (decision support system) to help growers, orchard managers, and packing house managers* *by providing real-time access to harvest data (e.g. trace the picking crews in the field, know the number of collected bins from each orchard) that will facilitate informed decisions and harvest planning. In addition, this system can be used to improve accuracy of payroll by reimbursing pickers precisely for the weight of harvested fruit rather than the current system of piece-rate. In 2012 this integrated system was evaluated in sweet cherry and apple orchards in Washington. The weight of harvested fruit, time and location of every fruit drop were calculated accurately; all the data were transmitted wirelessly to the server and no errors were recorded.*

Keywords. *labor management, cloud-based software, RFID, embedded systems, arduino.*

Introduction

Specialty crops (fruits and vegetables, tree nuts, dried fruits and horticulture and nursery crops, including floriculture) have been identified as the fastest growing segment of agribusiness (Wall Street Journal, 2007). These crops require a significant amount of labor for planting, pruning, thinning, and harvesting. They are characterized by high costs of production, and high crop value. Harvest costs are often the greatest expense for specialty crop producers, generally because harvest depends predominantly upon manual labor. The window for harvesting fruit crops at optimum maturity can be very sort. For example, harvesting sweet cherries prematurely or beyond optimal timing undermines consumer satisfaction with the fruit (Chauvin et al., 2009). Hence, proper tactical harvesting decisions are essential to reduce costs and maintain fruit quality.

The timely collection of pertinent data is the first step making better decisions on the farm. Few systems and techniques have been developed and adopted for harvest/labor data monitoring for specialty crops. Schueller et al. (1999) developed and evaluated a yield monitoring system for citrus and Ampatzidis and Vougioukas (2009) developed a yield monitoring and traceability system for peach and kiwi-fruit using radio frequency identification (RFID) and barcode registration technologies. Additionally, Ampatzidis et al. (2011) designed and developed a wearable position recording system for orchard workers to track their position in relation to trees, where GPS data are typically unavailable. One of the main technical challenges for wireless data transfer in orchards is the interference from the tree structure (canopy, foliage). Vougioukas et al. (2013) investigated the influence of foliage on radio signal losses for wireless sensor network (WSN) in a plum orchard. Using XBee Pro® transceivers (Digi, Inc., Minnetonka, MN, USA) they found that at a distance of 120 m the ratio of lost packets was ~20%, and they estimated that the reliable range of this system is 50-70 m within the orchard. Hence, it is very important to develop an accurate data acquisition system to enhance real-time decision making. Erroneous interpretation of the collected data would lead to inappropriate decision making.

On the other hand, cloud computing (CC) is used worldwide, because it can improve flexibility, reduce infrastructure, streamline processes, improve accessibility, and efficiently handles large data sets. In general, it is a paid service usage model. In agriculture, CC has been used for real-time visual monitoring of crop growth (Zhang, 2011), and for constructing and improving agricultural products supply chain (Qiu et al., 2010). Additionally, Teng et al. (2012) developed a web-based service to manage livestock (herb management). This system can improve data accessibility and provide up-to-date information to users.

In this paper, a harvest management information system with the ability of collecting, processing and visualizing harvest data in real-time is presented. This system can be used as a management tool by providing real-time access to harvest data. Furthermore, it can improve accuracy of payroll by reimbursing pickers precisely for the weight of harvested fruit, create yield maps, and improve field and fruit handling logistics.

Materials and Method

The Harvest Management Information System (HMIS) combines a real-time Labor Monitoring System (LMS) with a cloud-based harvest management software. Below, we briefly present the LMS and the main components of the cloud-based harvest management software.

Labor Monitoring Systems (LMS)

Generally, the LMS consists of: (i) a digital weighing system; (ii) a radio frequency identification (RFID) reader; (iii) a GPS; and (iv) a computational unit (CU) with a wireless transceiver. RFID tags, containing unique ID numbers, embedded within rubber wrist bands, are worn by pickers. This system can read a picker's ID (RFID bracelet), measure the weight of fruit, and record the time and location of every fruit drop as pickers empty their buckets directly into bins.

A prototype system for measuring average harvest efficiency, per picking crew, was developed in 2010

(Ampatzidis et al., 2012a) and modified in 2011 (Ampatzidis et al., 2012b, Fig. 1) to a real-time labor monitoring system (LMS) with the ability to track and record individual picker efficiency. Additionally, portable Labor Monitoring Systems (PLMS) were designed and developed for tree fruit crops (e.g. for apples, Fig. 2). All these systems/prototypes were utilized to collect real-time data during harvest of specialty crops. The collected data can be transmitted wirelessly to the server in real-time with an internet or GPRS connection. A detailed description of a LMS is given in Ampatzidis et al. (2012b).

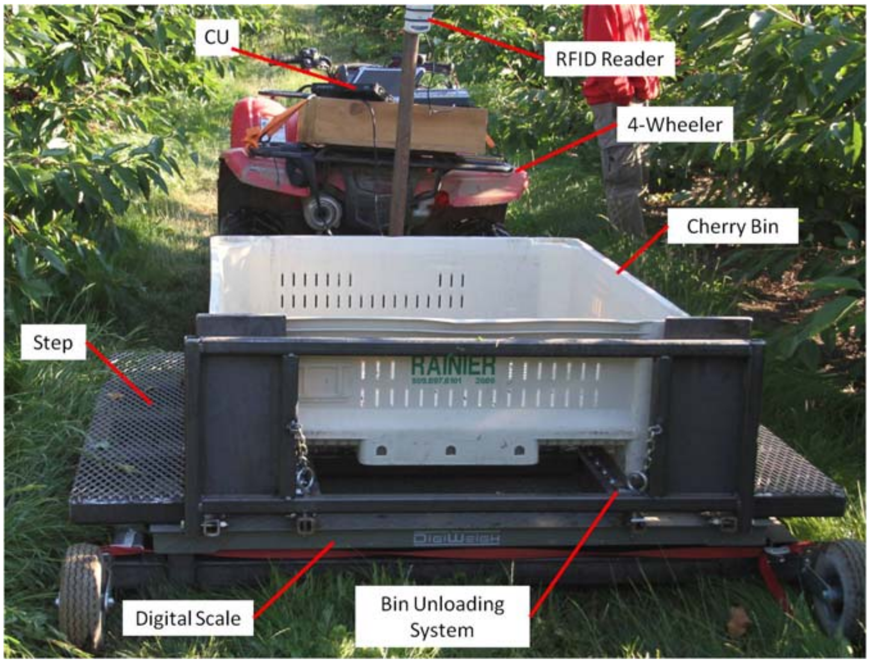

Figure 1. Real-time novel Labor Monitoring System (LMS) (CU= computational unit, RFID=radio frequency identification).

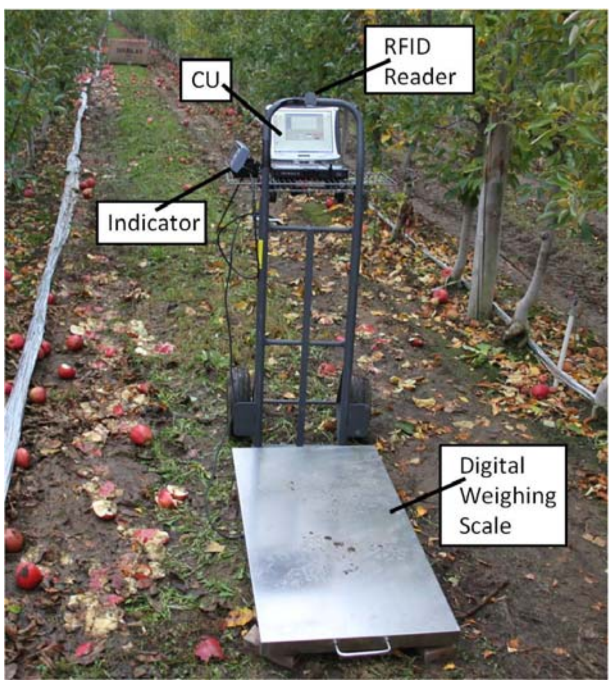

Figure 2. Example of a Portable Labor Monitoring System (PLMS) for apples (CU= computational unit, RFID=radio frequency identification).

A CU was developed to collect data from the sensors (RFID reader, GPS, weighing system), process and wirelessly transmit them to the cloud-based harvest management software. The CU contains: (i) a microcontroller (arduino mega 2560 R3); (ii) a display unit; (iii) a real-time clock; (iv) a secure digital (SD) memory card (for back-up); (v) a wireless transceiver –Zigbee (2.4 GHz Xbee, 1mW wire antenna, Sparkfun Electronics); (vi) a thermal printer; (vii) two RS232 ports, a buzzer, buttons (Fig. 3).

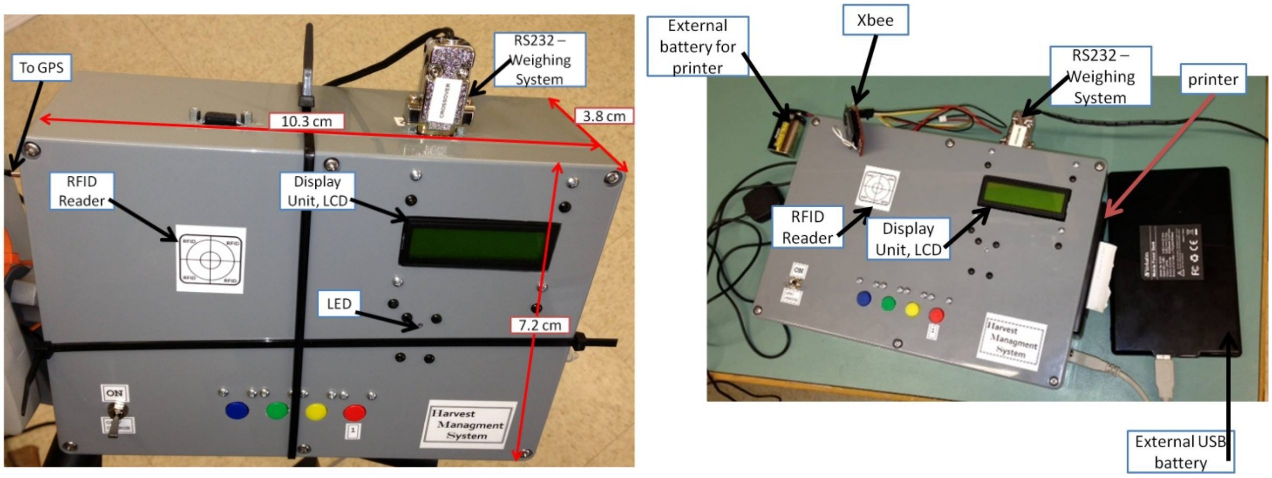

Figure 3. Computational Unit (CU) for the LMS; collect, process and wirelessly transmit the harvest data.

The LMS data can be used to create yield maps, improve field logistics, as well as, provide growers with the ability to pay pickers on weight of harvested fruit, rather than the current system of piece-rate. Furthermore, these systems (LMS) were utilized to investigate the role of training system on harvest rate of individual pickers (Ampatzidis and Whiting, 2013), and to compare the efficiency of future harvest technologies (Ampatzidis et al., 2012c) in commercial sweet cherry (Prunus avium L.) orchards. Tests show that the LMS does not interfere significantly with the commercial harvest process (Ampatzidis et al., 2012d).

Cloud-based Harvest Management Software

The cloud-based harvest management software includes a web portal through which any LMS can transmit harvest data wirelessly to the cloud-based system. A session-based communication protocol was designed and implemented, using Ruby on Rails, for transferring the harvest data (Tan et al., 2013). This protocol uses specific HTTP methods and allows the cloud-based software to interact with multiple LMSs. The LMS data are encapsulated in JavaScript Object Notation (JSON), a JavaScript-based open standard designed for exchanging data. In this implementation, the LMS transmit data using a HTTP POST request. If the record is successfully saved in the database a status code is returned to the LMS (Tan et al., 2013). The cloud-based software is deployed on a Platform-as-a-Service (PaaS) cloud-computing platform. This platform can be used through a variety of internet-connected devices, including Apple iPad and other tablet devices.

Additionally, a data analysis and visualization module was developed that can visualize the harvest data in real time, (e.g. produce labor-based figures and tables, payroll reports etc). Fig. 4a shows a screen shot of the employ page, where a grower or field manager can add, edit or delete employs, and Fig. 4b shows a screen shot of harvest data record/table for a selected picking crew.

a) b)

Figure 4. HMIS web interface. Screen shot of the: a) employ page, and b) harvest data record/table for a selected picking crew.

Experimental design

Testing was conducted in an experimental sweet cherry (*Prunus avium* L.) orchard, at the WSU Roza experimental farm, near Prosser, WA. The orchard was comprised of 6-year-old block of 'Selah' on 'Gisela®6' rootstock trees planted at an inter-row spacing of 2 m and intra-row spacing of 3 m. The trees were trained to a planar architecture comprised of unbranched vertical fruiting wood (Upright Fruiting Offshoots-UFO, Fig 5). The average height of the trees was 2.5-3 m and the width of the trees canopy 0.5 m.

On 13 July, 2012 nine pickers harvested fruit using 3 m ladders. The picking crew moved along tree rows picking into buckets secured over their shoulders with straps. The capacity of the picking bucket is determined by the orchard manager and generally is 9 kg. Once the bucket is filled, the picker will dump fruit into a bin (whose capacity is ca. 180 kg). The LMS was used to collect, process and wirelessly transmit the harvest data to the cloud-based harvest management software.

Figure 5. Sweet Cherry orchard trained to a planar architecture comprised of unbranched vertical fruiting wood (Upright Fruiting Offshoots-UFO).

Results and Discussion

The LMS automated collection of the harvest data: the picker's ID, weight of harvested fruit, time and location of every fruit drop were recorded. All the data were transmitted wirelessly to the server and no errors were recorded. The cloud-based software received and processed the LMS data on labor activities. It visualized the collected data, and extracted the data necessary for management information and automated filling of documents. For example, Fig. 6 shows the tree map of the experimental sweet cherry orchard. In this map, the cloud-based software visualizes the location of each harvested bin, the final weight of the fruit inside the bin, as well as the time when a bin is full. Additionally, it shows, in real time, the "status" of the "current" bin (the bin that the pickers use to empty their buckets at the current time) e.g. at 10:44 am, the weight of fruit inside the "current" bin is 83.65 kg (Fig. 6).

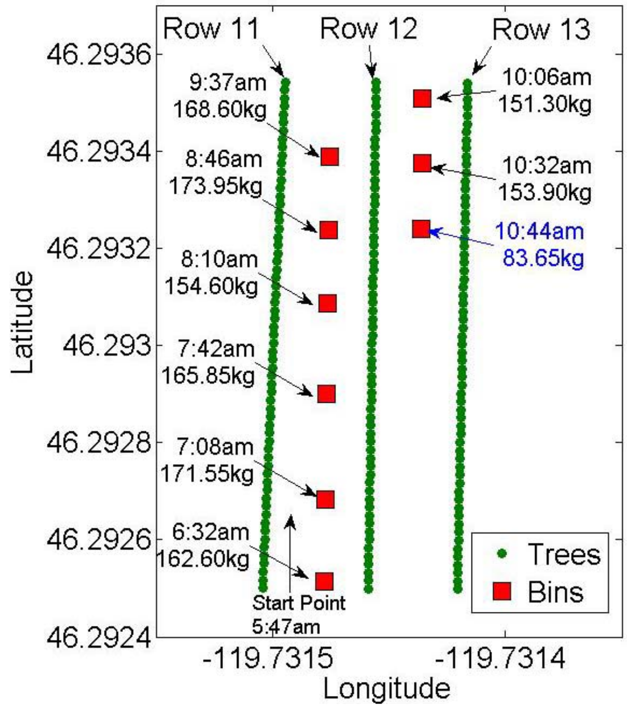

Figure 6. Example of sweet cherry harvest data: time and location of each full bin during harvest. At 10:44 am the weight of the fruit inside the "current" bin is 83.65 kg (blue color).

The LMS revealed significant variability among final bin weights. This variability is attributed to the ability of the picking crew and/or the orchard manager's judging of when bins are full. For example, in the experimental sweet cherry orchard, the final bin weight (ostensibly full) varied between 151.30 kg to 173.95 kg (Fig. 6), a difference of almost 23 kg (mean=162.80 kg ± 8.6 kg).

Additionally, the cloud-based harvest management software can plot, in real time, the weight of harvested fruit for each picker and bin. Fig. 7 visualizes the weight of fruit for every fruit drop, for the nine pickers, during harvest (in real-time). Currently, tree fruit growers pay pickers by piece-rate – for full bins or buckets which are judged to be full visually by the orchard manager or an additional employee. There is no accurate system for calculating labor efficiency or reimbursing pickers individually. It is in the pickers' interest to minimize the quantity of fruit per bin or bucket. The LMS data with picking weights assigned to individual pickers can be used to provide growers with the ability to pay pickers on weight of harvested fruit rather than piece-rate. Hence, at the end of each harvest day, the cloud-based software uses the information from the LMS to compute the compensation for each picker (e.g. Fig. 8).

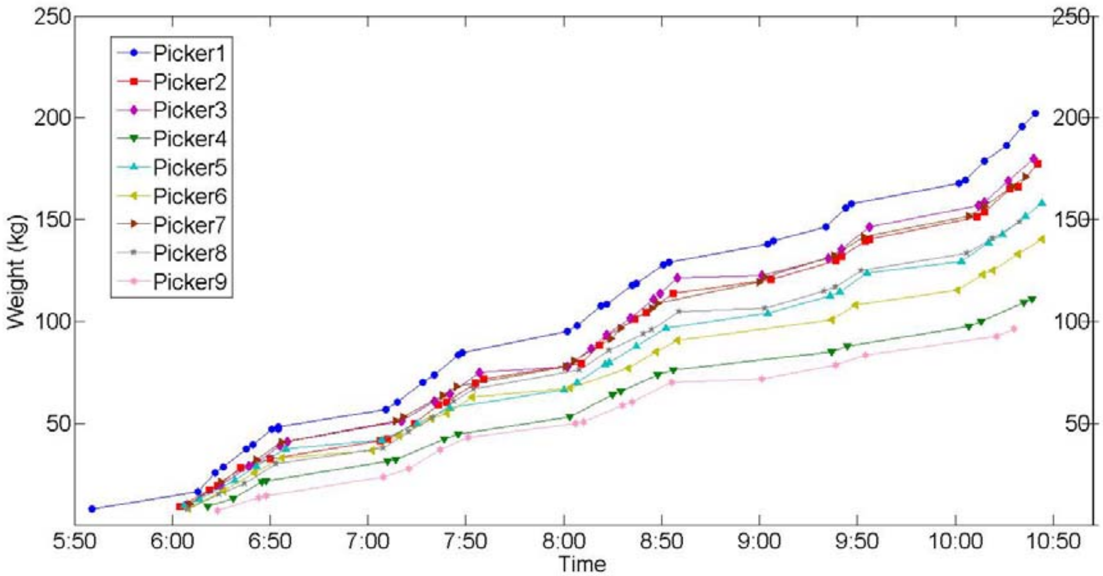

Figure 7. Harvest data for a 'Selah'/'Gisela®6' orchard picked on 13 July, 2012. The cloud-based software visualizes the weight of harvested fruit for each picker during harvest (in real-time). There were 9 pickers in the crew.

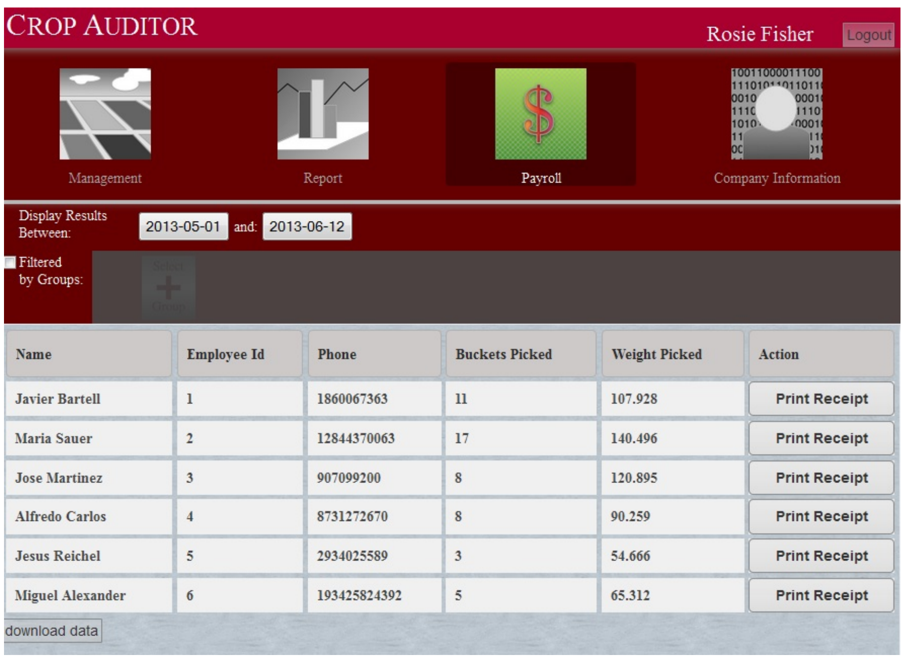

Figure 8. The HMIS automated produce accurate payroll records (screen shot). Using the HMIS growers can pay pickers on weight of harvested fruit rather than piece-rate.

Conclusion

We developed a Harvest Management Information System (HMIS) that provides real-time access to harvest data. This integrated system combines a Labor Monitoring System (LMS) with a cloud-based harvest management software. The LMS collects, in real-time, harvest and labor data and wirelessly transmits them to the cloud-based platform. The harvest management software analyses and visualizes the collected data, producing figures, tables and payroll records. Additionally, it can automated develop yield maps, using the geo-referenced labor data from the LMS, helping farmers to visualize the productivity of their farms and investigate factors affecting the yield (spatially). The HMIS provides real-time access to visualized results using a variety of internet-connected devices, such as mobile devices and tablets.

The HMIS can be used as a management tool (decision support system) to:

- provide real-time access to harvest data (e.g. trace the picking crews in the field, know the number of collected bins from each orchard).
- simplify data analysis process; visualize the harvest and labor data; produce yield maps; automated fill documents (e.g. payroll and labor productivity records).
- improve accuracy of payroll by reimbursing pickers based on the actual weight of harvested fruit rather than the current system of piece-rate.
- enhance real-time decision making and fruit handling logistics.
- provide "in-field" traceability information: associate fruit-producing tree(s), with bins and pickers.

Acknowledgements

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