Cloud-Based Harvest Management Information System for Hand-Harvested Specialty Crops

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Abstract

The harvest process for specialty crops is generally one of intensive activity because many people are required for harvest and packing, and the harvest window is brief due to the high perishability of the produce. Herein we present a cloud-based Harvest Management Information System (HMIS) that combines a novel real-time Portable Labor Monitoring System (PLMS) with a cloud-based harvest management software. The PLMS comprised of three key elements (1) a self-leveling scale, (2) electronic control box, and (3) a frame that supports all hardware. The electronic control box includes: (i) a RFID reader, (ii) a LCD display, (iii) a thermal printer, (iv) a GPS module, and (v) a communication system. 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 (optional) of every fruit 'transaction' (i.e., every time a

picker brings a bucket of fruit to the collection bin). The collected data can be transmitted wirelessly to the server in real-time. The cloud-based software receives and processes the PLMS 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 is unique in its ability to: 1) accurately credit pickers for the fruit they have harvested in the field without impeding or altering the harvest process, 2) streamline data entry to payroll, 3) provide real-time tracking of harvest, yield mapping, and traceability, and, 4) generate precise and reliable harvest efficiency data. This integrated system was evaluated in sweet cherry, blueberry and apple orchards in Washington, USA. 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.

1. 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 generally require a significant amount of labor for planting, pruning, thinning, and, in particular, harvesting. They are characterized by high costs of production, and high crop value. Harvest costs are often the greatest expense for specialty crop producers, because harvest depends predominantly upon manual labor. The window for harvesting fruit crops at optimum maturity can be very short, placing great importance on the harvest process. For example, harvesting sweet cherries prematurely or beyond optimal timing undermines consumer satisfaction with the fruit (Chauvin et al., 2009).

The timely collection of pertinent data is the first step toward making better harvest-related 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 (i.e., canopy and wood). 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 around 20%, and they estimated that the reliable range of this system is 50-70 m within the orchard. Ampatzidis et al. (2015) developed a low-cost WSN using aerial systems in orchards. They evaluated the connection limitations, through the tree canopies, between a ground-based WSN and Unmanned Aerial Vehicles -UAVs. This integrated system can provide real-time access to high quality data in order to quickly and accurately identify problems. Wang et al. (2006) presented an overview on wireless sensors development in agriculture and food industry, and Ruiz-Garcia and Lunadei (2011) explored the advantages, limitations and challenges of the RFID-based systems for identification, tracking and timely data collection in agriculture. Cunha et al. (2010) developed a user-friendly system for exchanging contextualized information and accessing contextualized services in vineyards, using mobile devices and multi-tag technologies. It is important to develop an accurate data acquisition system to enhance real-time decision making. To streamline harvest operations, the number of workers and machines required to harvest, handle, and transport the product needs to be planned along with the execution of field operations (Ampatzidis et al., 2014).

We hypothesize that accurate data acquisition systems can also be used to improve accuracy of

72 payroll. Various methods for reimbursing pickers have been employed worldwide, with most fruit
73 growers now paying a piece-rate to small picking teams for bins (e.g. for pome fruit) or for buckets
74 (e.g. for sweet cherries, blueberries). Regardless, paying piece-rate (pay pickers per full of fruit
75 buckets or bins, assuming that their weights are similar; but might be under- or overfilled) is beset
76 with inaccuracies that cause significant financial losses. Tests in commercial sweet cherry, apple and
77 blueberry orchards revealed variability of 25 – 30% of final weight among bins and buckets
78 (Ampatzidis et. al, 2012; Ampatzidis et. al, 2013; Ampatzidis and Whiting, 2013). For example, in
79 sweet cherry orchards a range of more than 50 kg in bin weights (mean bin weight~200 kg) and 3 kg
80 in bucket weight (mean bucket weight~10 kg) were recorded during these trials. These discrepancies
81 can cause significant economic losses. A cherry grower found that pickers were overpaid \$16,663 in
82 2010 and 2011 because of the variability in bucket weights (Growing Produce article, 2013).
83 Additionally, a blueberry grower in Prosser, WA (USA) estimated that pickers were overpaid \$20,000
84 in one week (2013).

85 Cloud computing (CC) is used worldwide, because it can improve flexibility, reduce infrastructure,
86 streamline processes, improve accessibility, and efficiently handles large data sets. In general, it is a
87 paid service usage model. In agriculture, CC has been used for real-time visual monitoring of crop
88 growth (Zhang, 2011), and for constructing and improving agricultural products supply chain (Qiu et
89 al., 2010). Additionally, Teng et al. (2012) developed a web-based service to manage livestock (herb
90 management). This system can improve data accessibility and provide up-to-date information to users.
91 Farm Management Information Systems (FMIS) are used for collecting and processing data to assist
92 growers to manager their farms efficiently (Fountas et al., 2015). Kaloxylos et al. (2014) presented the
93 architecture and implementation of a cloud-based FMIS that could serve as a marketplace for services
94 for the farmers. These systems improve operational planning and optimize the work performed in the
95 fields (Ampatzidis et al., 2014; Fountas et al., 2006; Sørensen et al., 2011).

In this paper, a harvest management information system (HMIS) 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. It can improve accuracy of payroll by reimbursing pickers precisely for the weight of harvested fruit rather than the current system of piece-rate. 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 HMIS combines a real-time Portable Labor Monitoring System (PLMS) with a cloud-based harvest management software. Below, we briefly present the PLMS and the main components of the cloud-based harvest management software.

Portable Labor Monitoring Systems (PLMS)

Generally, the portable PLMS consists of: (1) a self-leveling scale, (2) electronic control box (or Computational Unit –CU), and (3) a frame that supports all hardware. The electronic control box includes: (i) a RFID reader, (ii) a LCD display, (iii) a thermal printer, (iv) a GPS module, and (v) a communication system. 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.

118 Additionally, a Portable Labor Monitoring Systems (PLMS) were designed and developed for tree
119 fruit crops (Fig. 2) (Ampatzidis and Whiting, 2014). All these systems/prototypes were utilized to
120 collect real-time data during harvest of specialty crops. The collected data can be transmitted
121 wirelessly to the server in real-time with an internet or GPRS connection. A detailed description of a
122 LMS is given in Ampatzidis et al. (2012b) and of a PLMS in (Ampatzidis and Whiting, 2014).

123

124 Figure 1. Real-time novel Labor Monitoring System (LMS) (CU= computational unit, RFID=radio
125 frequency identification) (Ampatzidis et al., 2012b).

126

Figure 2. Portable Labor Management System (PLMS) mounted on a cherry bin. It consists of a digital hanging-weight scale (S-type load cell), and a computational unit (CU).

A computational unit 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, USA); (vi) a thermal printer; and (vii) two RS232 ports (Fig. 3).

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

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141 Each picker places their bucket(s) on the suspended platform of the PLMS and initiates the weighing
142 system with their RFID-wristband by passing it before the reader. Figure 4 presents the PLMS work
143 flow. The PLMS simultaneously reads the picker ID (RFID tag), measures the weight of fruit,
144 associates it with the picker ID, and prints a receipt (Fig. 5) that outlines the picker's ID, date, time,
145 bucket(s) weight, and accumulated weight (total weight). The collected data are stored locally to an
146 SD card and transmitted wirelessly to the cloud (in real time). A cloud-based harvest management
147 software has developed to receive, process and visualize the PLMS data. It extracts the data necessary
148 for management information and automated filling of documents (e.g. payroll, yield maps).
149 For the PLMS, the worker should place his bucket onto the scale (Fig. 2) and wave his wrist RFID tag
150 in front of the scanner. After a confirmation beep, the device would displaying information regarding
151 the worker and his payload (date-time, worker ID, fruit weight for this transaction, total fruit weight),
152 and print out this information through the thermal printer. The ticket (Fig. 5) would then be taken by
153 the worker and remove the bucket off the scale. The information will then be recorded to a SD card
154 for data collection at the end of the work period of all worker transactions.

155

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Figure 4. The PLMS work flow.

Figure 5. The outlines the picker's ID (P), date, time, bucket(s) weight (BW in kg or lb), and accumulated weight (total weight, TW in kg or lb).

The PLMS 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 and PLMS) 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 PLMS does not interfere significantly with the commercial harvest process (Ampatzidis et al., 2012d).

Cloud-based Harvest Management Software

A novel aspect of our system is the use of cloud-based software to acquire, process, and visualize data received from PLMS hardware. Cloud computing refers to a practice of using a shared pool of configurable computing resources to enable ubiquitous, convenient, and on-demand access (Mell & Grance, 2011). Cloud computing is an ideal platform to address the scalability and flexibility required

for processing harvest data. The demand for data processing varies greatly on and off a harvest season. The resource provisioning feature of cloud computing enables us to dynamically allocate computing resources on-the-fly as needed. For example, when the demand for data processing rises, the system requests more server instances to satisfy the demand. Our cloud-based web software also means that we can provide services to farmers among a geographically dispersed area, through web browsers on a variety of Internet-connected devices.

Figure 6 Architecture design of cloud-based software (Tan, Haley, and Wortman, 2015).

Figure 6 shows the architecture design of our cloud-based software and affiliated hardware. The software includes a device portal hosted on a data acquisition server. A PLMS hardware sends real-time harvest data through the portal. The device portal uses a HTTP-based protocol specifically designed for transferring harvest data (Tan et al., 2013). The data is encapsulated in JavaScript Object Notation – JSON- (Oracle, USA), and transmitted to the portal by a PLMS device using HTTP POST method. A status code representing the validity of data is returned to the PLMS device. The protocol uses a session-based design to improve the efficiency of data transferring (Tan et al., 2013). The data

191 grouped in the same session share the same spatial (e.g. the GPS location of a device) and other
192 session-specific information, saving the time and power otherwise spent on transmitting this
193 information separately for each record.

194 After receiving the data, the software processes the data and associates them with appropriate pickers.
195 A specific issue in accruing harvest labor is the existence of complex many-to-many employment
196 relations: an employer often hires multiple pickers, and a picker may work for more than one
197 employer concurrently. Using a patented technology (Tan, 2015), the cloud-based software can
198 accurately associate a harvest record with the picker, even for multiple organizations sharing the same
199 labor pool.

200 A benefit of our cloud-based software is its ability of integrating and visualizing data. The software
201 has a data analysis and visualization module which can show a variety of information, from real-time
202 productivity of individuals and groups, to payroll reports, to yield map. Harvest data collected by
203 PLMS hardware provides a non-invasive way to measure yield. We developed a yield map module to
204 visualize yield map using harvest data (Tan and Wortman, 2014). A feature of our yield map module
205 is that it allows to define yield distribution from a collection point (e.g. PLMS hardware) to trees,
206 based on the characteristics of an orchard operation. Fig. 7a shows a screen shot of the employ page,
207 where a grower or field manager can add, edit or delete employs, and Fig. 7b shows a screen shot of
208 harvest data record/table for a selected picking crew.

209

210

a)

b)

211 Figure 7. Cloud-based web interface. Screen shot of the: a) employ page, and b) harvest data
212 record/table for a selected picking crew.

213

214 The cloud-based software is deployed on Amazon Web Service (USA), a leading Platform-as-a-
215 Service (PaaS) cloud-computing platform. The scalability of Amazon cloud enables to serve multiple
216 farmers concurrently, without compromising performance. A farmer can access our web interface
217 through a web browser, and the interface design is optimized for tablets and other mobile devices,
218 with a touch-friendly design.

219 Experimental design

220 Testing was conducted in an experimental sweet cherry (*P. avium*) orchard, at the WSU Roza
221 experimental farm, near Prosser, WA. The orchard was comprised of 6-year-old block of 'Selah' on
222 'Gisela®6' rootstock trees planted at an inter-row spacing of 2 m and intra-row spacing of 3 m. The

223 trees were trained to a planar architecture comprised of unbranched vertical fruiting wood (Upright
224 Fruiting Offshoots-UFO; Whiting, 2009). The average height of the trees was 2.5-3 m and the width
225 of the trees canopy 0.5 m.

226 On 13 July, 2012 nine pickers harvested fruit using 3 m ladders. The picking crew moved along tree
227 rows picking into buckets secured over their shoulders with straps. The capacity of the picking bucket
228 (the definition of a full bucket) is determined by the orchard manager (or quality controller) and
229 generally is 9 kg. Once the bucket is filled, the picker will dump fruit into a bin (whose capacity is ca.
230 180 kg). The PLMS was used to collect, process and wirelessly transmit the harvest data to the cloud-
231 based harvest management software.

232

233 **Results and Discussion**

234 The PLMS automated collection of the harvest data: the picker's ID, weight of harvested fruit, time
235 and location of every fruit drop were recorded. All data were transmitted wirelessly to a cloud-based
236 server and no errors were recorded. The cloud-based software received and processed the PLMS data
237 on labor activities. It displayed the collected data, and extracted the data necessary for management
238 information and automated filling of documents. For example, Fig. 8 shows the tree map of the
239 experimental sweet cherry orchard. In this map, the cloud-based software visualizes the location of
240 each harvested bin, the final weight of the fruit inside the bin, as well as the time when a bin is full.
241 Additionally, it shows, in real time, the "status" of the "current" bin (the bin that the pickers use to
242 empty their buckets at the current time) e.g. at 10:44 am, the weight of fruit inside the "current" bin is
243 83.65 kg (Fig. 8).

244

Figure 8. 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 PLMS 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. 9), a difference of almost 23 kg (mean=162.80 kg $\pm$ 8.6 kg). Variation in final bin weight may also be due to differences in fruit size. Smaller fruit settle in the bin more than large fruit and this leads to higher bin weight. There is concern for over-filling bins and its negative effects on fruit quality. The PLMS would allow growers to precisely monitor fruit weight in each bin and make informed decisions on when to move to a new bin.

The cloud-based harvest management software can plot, in real time, the weight of harvested fruit for each picker and bin (Fig. 9). 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

259 is no more accurate system for calculating labor efficiency nor for reimbursing pickers more
 260 precisely. It is in the pickers' interest to minimize the quantity of fruit per bin or bucket. The PLMS
 261 data, with picking weights assigned to individual pickers, can be used to provide growers with the
 262 ability to pay pickers on weight of harvested fruit rather than piece-rate. Pickers would therefore be
 263 able to receive credit for the fruit harvested at any moment (i.e., when it is convenient for them to do
 264 so rather than only when their bucket is sufficiently full). Pickers would be able to receive credit for
 265 half-full bucket, for example, and not need to carry around nearly 10 kg of fruit. We hypothesize that
 266 this will lead to improved picker efficiency and picker safety. Current research is investigating both
 267 hypotheses. Using the system we describe herein, at the end of each harvest day, the cloud-based
 268 software can utilize the information from the PLMS to compute the compensation for each picker
 269 (e.g. Fig. 10).

270 The advantages of paying by weight over the current piece-rate reimbursement system for specialty
 271 crop producers are several fold, including improved accuracy/fairness of reimbursement (for both the
 272 picker and the farm owner), improved picker safety, eliminated disputes between pickers and
 273 management, improved fruit quality, improved harvest efficiency, and facilitated payroll data entry.

274

Figure 9. 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.

Name	Employee Id	Phone	Buckets Picked	Weight Picked	Action
Javier Bartell	1	1860067363	11	107.928	Print Receipt
Maria Sauer	2	12844370063	17	140.496	Print Receipt
Jose Martinez	3	907099200	8	120.895	Print Receipt
Alfredo Carlos	4	8731272670	8	90.259	Print Receipt
Jesus Reichel	5	2934025589	3	54.666	Print Receipt
Miguel Alexander	6	193425824392	5	65.312	Print Receipt

Figure 10. 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 Portable Labor Monitoring System (PLMS) with a cloud-based harvest management software. The PLMS 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 PLMS, 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. This proposed system could be linked to other plan pathology identification tools (e.g. Luvisi et al., 2014) and RFID-web 2.0 applications (e.g. Luvisi et al., 2012) for storing, updating and sharing plant-related information (e.g. for phytotechnology). The HMIS does not collect any personal information and workers have access to all the collected information related to them. This integrated system does not break any regulation, rule or law regarding workers' rights (e.g. protection of workers' personal data, Geneva, ISBN 92-2-110329-3).

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.

308

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403 **Figure captions**

404 Figure 1. Real-time novel Labor Monitoring System (LMS) (CU= computational unit, RFID=radio
405 frequency identification) (Ampatzidis et al., 2012b).

406 Figure 2. Portable Labor Management System (PLMS) mounted on a cherry bin. It consists of a
407 digital hanging-weight scale (S-type load cell), and a computational unit (CU).

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

410 Figure 4. The PLMS work flow.

411 Figure 5. The outlines the picker's ID (P), date, time, bucket(s) weight (BW in kg or lb), and
412 accumulated weight (total weight, TW in kg or lb).

413 Figure 6 Architecture design of cloud-based software (Tan, Haley, and Wortman, 2015).

414 Figure 7. Cloud-based web interface. Screen shot of the: a) employ page, and b) harvest data
415 record/table for a selected picking crew.

416 Figure 8. Example of sweet cherry harvest data: time and location of each full bin during harvest. At
417 10:44 am the weight of the fruit inside the "current" bin is 83.65 kg (blue color).

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

421 Figure 10. The HMIS automated produce accurate payroll records (screen shot). Using the HMIS
422 growers can pay pickers on weight of harvested fruit rather than piece-rate.

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