Computers and Electronics in Agriculture 122 (2016) 161–167

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Cloud-based harvest management information system for hand-harvested specialty crops

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ARTICLE INFO

Article history:
Received 26 September 2015
Received in revised form 21 December 2015
Accepted 29 January 2016
Available online 12 February 2016

Keywords:
Labor management
Cloud-based software
RFID
Embedded systems
Arduino

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.

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

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http://dx.doi.org/10.1016/j.compag.2016.01.032
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(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 payroll. Various methods for reimbursing pickers have been employed worldwide, with most fruit growers now paying a piece-rate to small picking teams for bins (e.g. for pome fruit) or for buckets (e.g. for sweet cherries, blueberries). Regardless, paying piece-rate (pay pickers per full of fruit buckets or bins, assuming that their weights are similar; but might be under- or overfilled) is beset with inaccuracies that cause significant financial losses. Tests in commercial sweet cherry, apple and blueberry orchards revealed variability of 25–30% of final weight among bins and buckets (Ampatzidis et al., 2012a,b,c,d; Ampatzidis and Whiting, 2013a,b). For example, in sweet cherry orchards a range of more than 50 kg in bin weights (mean bin weight ≅ 200 kg) and 3 kg in bucket weight (mean bucket weight ≅ 10 kg) were recorded during these trials. These discrepancies can cause significant economic losses. A cherry grower found that pickers were overpaid $16,663 in 2010 and 2011 because of the variability in bucket weights (Growing Produce article, 2013). Additionally, a blueberry grower in Prosser, WA (USA) estimated that pickers were overpaid $20,000 in one week (2013).

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. Farm Management Information Systems (FMIS) are used for collecting and processing data to assist growers to manager their farms efficiently (Fountas et al., 2015). Kaloxylos et al. (2014) presented the architecture and implementation of a cloud-based FMIS that could serve as a marketplace for services for the farmers. These systems improve operational planning and optimize the work performed in the fields (Ampatzidis et al., 2014; Fountas et al., 2006; Sørensen et al., 2001).

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.

2. 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.

3. 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. Additionally, a Portable Labor Monitoring Systems (PLMS) were designed and developed for tree fruit crops (Fig. 2) (Ampatzidis and Whiting, 2014). 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) and of a PLMS in (Ampatzidis and Whiting, 2014).

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

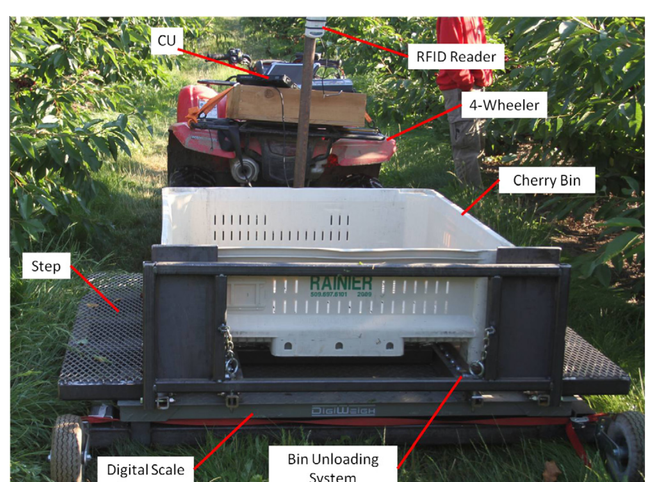

Fig. 1. Real-time novel Labor Monitoring System (LMS) (CU = computational unit, RFID = radio frequency identification) (Ampatzidis et al., 2012b).

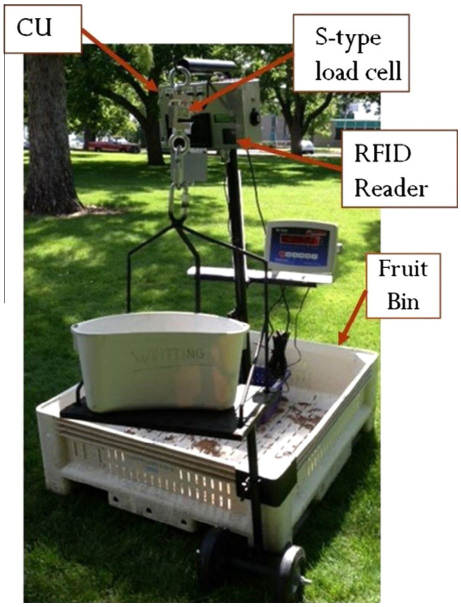

Fig. 2. Portable Labor Management System (PLMS) mounted on a cherry bin. It consists of a digital hanging-weight scale (S-type load cell), and a computational unit (CU).

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, 1 mW wire antenna, Sparkfun Electronics, USA); (vi) a thermal printer; and (vii) two RS232 ports (Fig. 3).

Each picker places their bucket(s) on the suspended platform of the PLMS and initiates the weighing system with their RFID-wristband by passing it before the reader. Fig. 4 presents the PLMS work flow. The PLMS simultaneously reads the picker ID (RFID tag), measures the weight of fruit, associates it with the picker ID, and prints a receipt (Fig. 5) that outlines the picker's ID, date, time, bucket(s) weight, and accumulated weight (total weight). The collected data are stored locally to an SD card and transmitted wirelessly to the cloud (in real time). A cloud-based harvest management software has developed to receive, process and visualize the PLMS data. It extracts the data necessary for management information and automated filling of documents (e.g. payroll, yield maps).

For the PLMS, the worker should place his bucket onto the scale (Fig. 2) and wave his wrist RFID tag in front of the scanner. After a confirmation beep, the device would displaying information regarding the worker and his payload (date-time, worker ID, fruit weight for this transaction, total fruit weight), and print out this

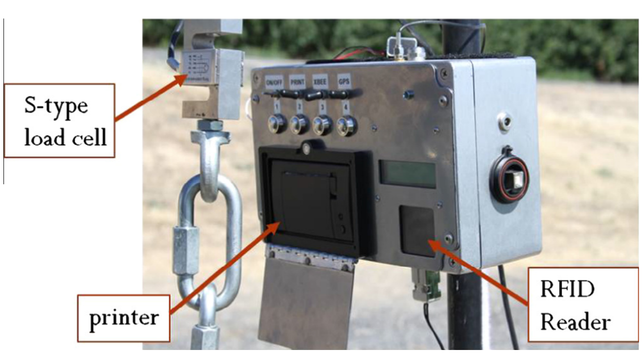

Fig. 3. Computational Unit (CU) for the PLMS; collect, process and wirelessly transmit the harvest data.

information through the thermal printer. The ticket (Fig. 5) would then be taken by the worker and remove the bucket off the scale. The information will then be recorded to a SD card for data collection at the end of the work period of all worker transactions.

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, 2013a,b), 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).

4. 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 and 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.

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

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

A benefit of our cloud-based software is its ability of integrating and visualizing data. The software has a data analysis and visualization module which can show a variety of information, from real-time productivity of individuals and groups, to payroll reports, to yield map. Harvest data collected by PLMS hardware provides a non-invasive way to measure yield. We developed a yield map module to visualize yield map using harvest data (Tan and Wortman, 2014). A feature of our yield map module is that it allows to define yield distribution from a collection point (e.g. PLMS hardware) to trees, based on the characteristics of an orchard operation. Fig. 7a shows a screen shot of the employ page, where a

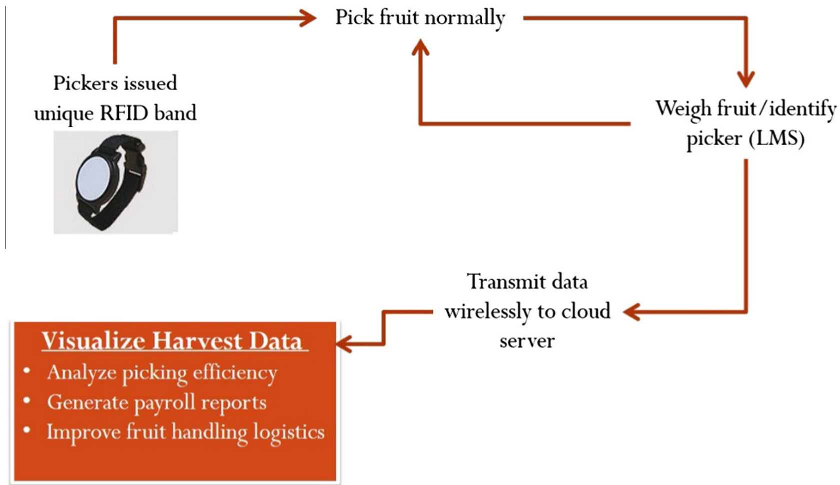

Fig. 4. The PLMS work flow.

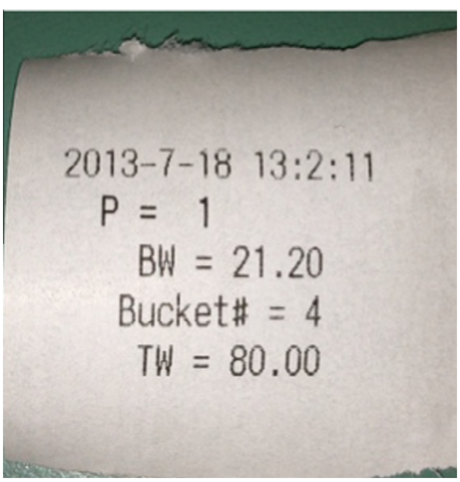

Fig. 5. The outlines the picker's ID (P), date, time, bucket(s) weight (BW in kg or lb), and accumulated weight (total weight, TW in kg or lb).

grower or field manager can add, edit or delete employs, and Fig. 7b shows a screen shot of harvest data record/table for a selected picking crew.

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

5. Experimental design

Testing was conducted in an experimental sweet cherry (*P. avium*) 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

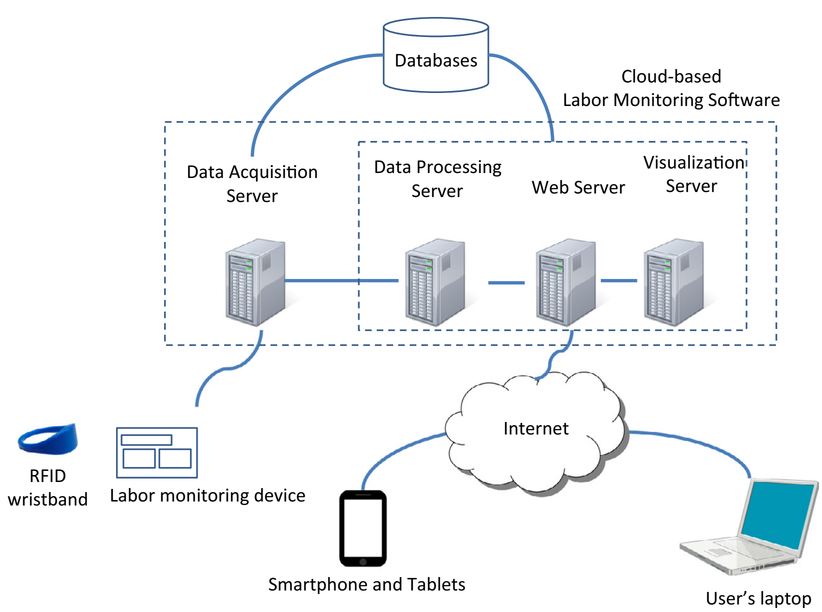

Fig. 6. Architecture design of cloud-based software (Tan et al., 2015).

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

(Upright Fruiting Offshoots-UFO; Whiting, 2009). 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 (the definition of a full bucket) is determined by the orchard manager (or quality controller) 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 PLMS was used to collect, process and wirelessly transmit the harvest data to the cloud-based harvest management software.

6. Results and discussion

The PLMS automated collection of the harvest data: the picker's ID, weight of harvested fruit, time and location of every fruit drop were recorded. All data were transmitted wirelessly to a cloud-based server and no errors were recorded. The cloud-based software received and processed the PLMS data on labor activities. It displayed the collected data, and extracted the data necessary for management information and automated filling of documents. For example, Fig. 8 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. 8).

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 and 173.95 kg (Fig. 9), a difference of almost 23 kg

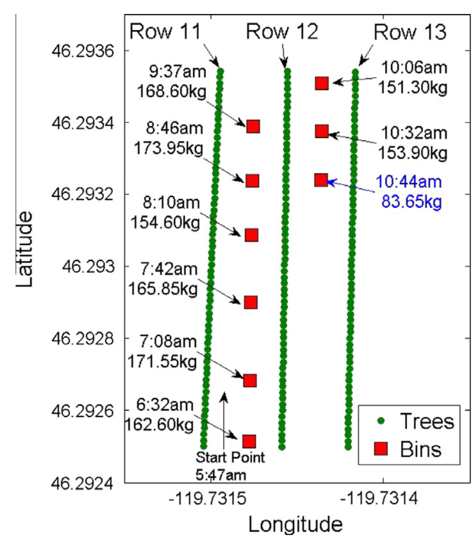

Fig. 8. Example of sweet cherry harvest data: time and location of each full bin during harvest. At 10:44 am the weight of the fruit inside the "current" bin is 83.65 kg (blue color). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(mean = 162.80 kg ± 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 is no more accurate system for calculating labor efficiency nor for reimbursing pickers

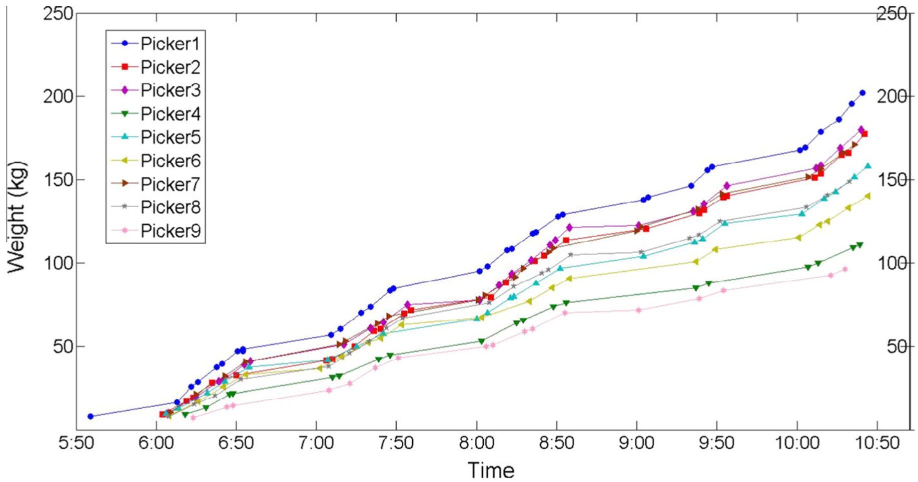

Fig. 9. Harvest data for a 'Selah'/'Gisela®6' orchard picked on 13 July, 2012. The cloud-based software visualizes the weight of harvested fruit for each picker during harvest (in real-time). There were 9 pickers in the crew.

more precisely. It is in the pickers' interest to minimize the quantity of fruit per bin or bucket. The PLMS 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. Pickers would therefore be able to receive credit for the fruit harvested at any moment (i.e., when it is convenient for them to do so rather than only when there bucket is sufficiently full). Pickers would be able to receive credit for half-full bucket, for example, and not need to carry around nearly 10 kg of fruit. We hypothesize that this will lead to improved picker efficiency and picker safety. Current research is investigating both hypotheses. Using the system we describe herein, at the end of each harvest day, the cloud-based software can utilize the information from the PLMS to compute the compensation for each picker (e.g. Fig. 10).

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

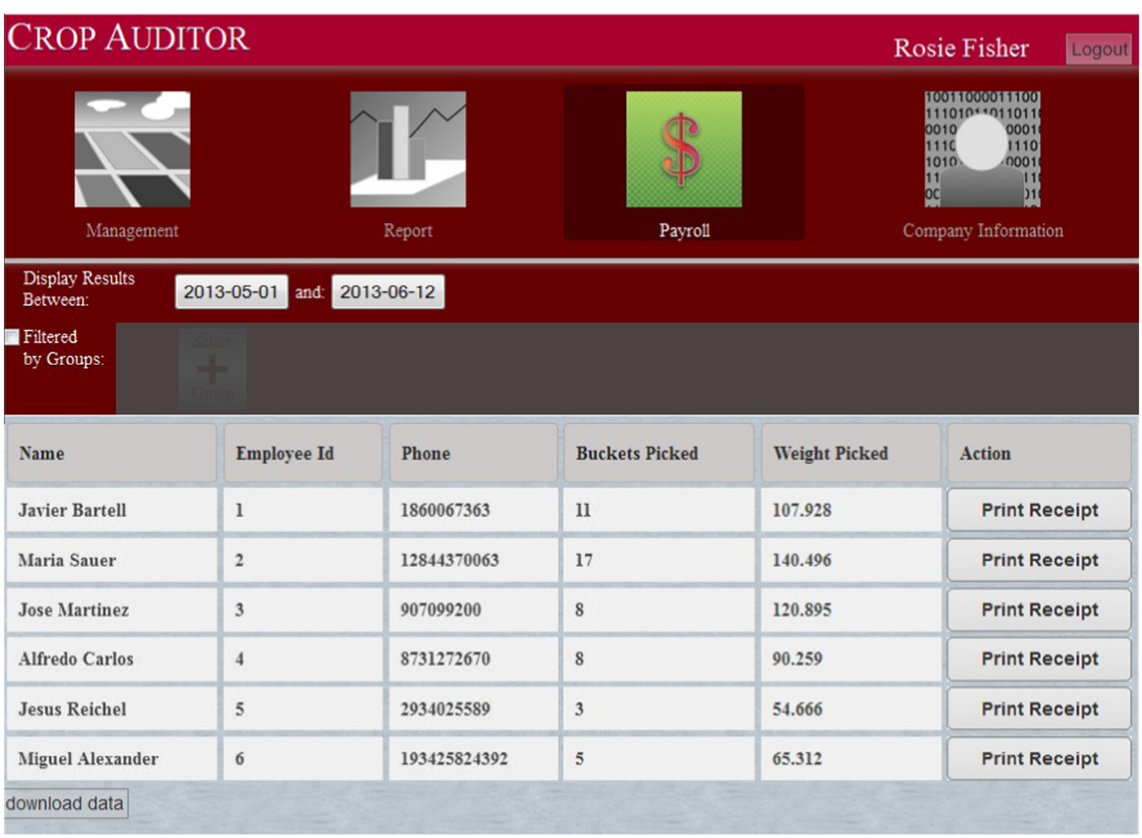

Fig. 10. The HMIS automated produce accurate payroll records (screen shot). Using the HMIS growers can pay pickers on weight of harvested fruit rather than piece-rate.

7. 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.

Acknowledgements

This research was supported in part by Washington State University Agricultural Research Center federal formula funds, Project Nos. WNP0745, WNP0728, and WNP0420 received from the U. S. Department of Agriculture National Institutes for Food and Agriculture, USDA-Specialty Crop Research Initiative project 2009-02559, Washington State University Center for Precision & Automated Agricultural Systems. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

References

Ampatzidis, Y.G., Vougioukas, S.G., Whiting, M.D., Zhang, Q., 2014. Applying the machine repair model to improve efficiency of harvesting fruit. Biosyst. Eng. 120 (April), 25–33.

Ampatzidis, Y.G., Whiting, M. D., 2013a. A novel portable system for improving accuracy of reimbursement for fruit picking. In: Proc. 12th International Conference on Precision Agriculture (ICPA2014), July 20–23, Sacramento CA, USA.

Ampatzidis, Y.G., Whiting, M.D., 2013b. Training system affects sweet cherry harvest efficiency. HortScience 45 (5), 547–555.

Ampatzidis, Y.G., Whiting, M.D., Liu, B., Scharf, P.A., Pierce, F.J., 2012a. Portable weighing system for monitoring picker efficiency during manual harvest of sweet cherry. Precision Agric. 14 (2), 162–171.

Ampatzidis, Y.G., Whiting, M.D., Scharf, P.A., Zhang, Q., 2012b. Development and evaluation of a novel system for monitoring harvest labor efficiency. Comput. Electr. Agr. 88, 85–94.

Ampatzidis, Y.G., Zhang, Q., Whiting, M.D., 2012c. Comparing the efficiency of future harvest technologies for sweet cherries. Acta Hort. (ISHS) 965, 195–198, <http://www.actahort.org/books/965/965_26.htm>.

Ampatzidis, G.Y., Adhikari, B., Scharf, P.A., Whiting, M.D., Zhang, Q., 2012d. Preliminary Testing of a System for Evaluating Picker Efficiency in Tree Fruit. ASABE Paper No. 121338439. St. Joseph, Mich.: ASABE.

Ampatzidis, Y.G., Vougioukas, S.G., Whiting, M.D., 2011. An automated wearable system for real-time human position monitoring during manual fruit harvesting. Comput. Electr. Agr. 78, 222–230.

Ampatzidis, Y.G., Vougioukas, S.G., 2009. Field experiments for evaluating the incorporation of RFID and barcode registration and digital weighing technologies in manual fruit harvesting. Comput. Electr. Agr. 66 (2), 166–172.

Ampatzidis, Y., Ward, J., Ramirez, A., 2015. Autonomous integrated wireless sensor network using autonomous unmanned aerial vehicles in orchards. In: Proceedings of the ASABE 2015, Annual International Meeting, New Orleans, LA USA, July 26–29, 2015.

Chauvin, M.A., Whiting, M.D., Ross, C.F., 2009. The influence of harvest time on sensory properties and consumer acceptance of sweet cherries. HortTechnology 19, 748–754.

Cunha, C.R., Peres, E., Morais, R., Oliveira, A.A., Matos, S.G., Fernandes, M.A., Ferreira, P.J.S.G., Reis, M.J.C.S., 2010. The use of mobile devices with multi-tag technologies for an overall contextualized vineyard management. Comput. Electr. Agr. 73 (2), 154–164.

Fountas, S., Carli, G., Sørensen, C.G., Tsiropoulos, Z., Cavalaris, C., Vatsanidou, A., Liakos, B., Canavari, M., Wiebensohn, J., Tisserye, B., 2015. Farm management information systems: current situation and future perspectives. Comput. Electr. Agr. 115 (July), 40–50.

Fountas, S., Wulfsohn, D., Blackmore, S., Jacobsen, H.L., Pedersen, S.M., 2006. A model of decision making and information flows for information-intensive agriculture. Agric. Syst. 87, 192–210.

Growing Produce, 2013. Paying Fruit Pickers per Pound. <http://www.growingproduce.com/fruits/paying-fruit-pickers-per-pound>.

Kaloxylos, A., Groumas, A., Sarris, V., Katsikas, L., Magdalinos, P., Antoniou, E., Politopoulou, Z., Wolfert, S., Brewster, C., Eigenmann, R., Terol, C.M., 2014. A cloud-based farm management system: architecture and implementation. Comput. Electr. Agr. V100 (January), 168–179.

Luvisi, A., Panattoni, A., Rinaldelli, E., Pagano, M., Mannini, F., Gribaudo, I., Bandinelli, R., 2014. Application of tracking implants in grape hybrids: adjustments to production practices and new health-compliant methodologies. Comput. Electr. Agr. 108, 130–134.

Luvisi, A., Panattoni, A., Triolo, E., 2012. Electronic identification-based Web 2.0 application for plant pathology purposes. Comput. Electr. Agr. 84, 7–15.

Mell, P., Grance, T., 2011. The NIST Definition of Cloud Computing. US National Institute of STandards and Technology.

Qiu, Z., Wang, F., Zhang, Z., 2010. Research on self-constructed traceability system based on agri-food supply chain management. Guangdong Agr. Sci. 4, 246–250.

Ruiz-Garcia, L., Lunadei, L., 2011. The role of RFID in agriculture: applications, limitations and challenges. Comput. Electr. Agr. 79 (1), 42–50.

Schueller, J.K., Whitney, J.D., Wheaton, T.A., Miller, W.M., Turner, A.E., 1999. Low-cost automatic yield mapping in hand-harvested citrus. Comput. Electr. Agr. 23 (2), 145–154.

Sørensen, C.G., Pesonen, L., Bochtisc, D.D., Vougioukas, S.G., Suomi, P., 2001. Functional requirements for a future farm management information system. Comput. Electr. Agr. 76 (2011), 266–276.

Tan, L., 2015 (February 17). Systems and Methods for Collecting and Accruing Labor Activity Data Under Many-to-many Employment Relation and with Distributed Access. US Patent No. 8959594.

Tan, L., Haley, R., Wortman, R., 2015. Cloud-based harvest management system for specialty crops. In: Proceedings of IEEE 4th Symposium on Network Cloud Computing and Applications.

Tan, L., Haley, R., Wortman, R., Ampatzidis, Y.G., Whiting, M.D., 2013. An integrated cloud-based platform for labor monitoring and data analysis in precision agriculture. In: Proc. The 14th IEEE International Conference on Information Reuse and Integration, San Francisco, USA, August 14–16, 2013.

Tan, L., Wortman, R., 2014. Cloud-based monitoring and analysis of yield efficiency in precision farming. In: Proceedings of 15th IEEE Internal Conference on Information Reuse and Integration.

Teng, C.C., Brown, K., Caro, C., Nielsen, W., Wells, J., 2012. A service oriented livestock management system using occasionally connected mobile-cloud architecture. In Proc. Systems Conference (SysCon), 2012 IEEE International, Vancouver, British Columbia, Canada, 19–22 March, 2012.

Vougioukas, S., Anastassiu, H.T., Regen, C., Zude, M., 2013. Influence of foliage on path losses (PLs) for wireless sensor network (WSN) planning in orchard. Biosyst. Eng. 114, 454–465.

Wall Street Journal, Immigration non-harvest, Friday, July 20, 2007, A12.

Wang, N., Zhang, N., Wang, M., 2006. Wireless sensors in agriculture and food industry—recent development and future perspective. Comput. Electr. Agr. 50 (1), 1–14.

Whiting, M.D., 2009. Upright Fruiting Offshoots. Prosser, WA:WSU-IAREC.8Mar.2011. <http://fruit.prosser.wsu.edu/UFO.html>.

Zhang, M., 2011. Application of computer technology in modern agriculture. Agr. Eng. 1 (4), 26–28.