DEVELOPMENT AND TESTING OF A CITRUS YIELD MONITOR

S. D. Tumbo, J. D. Whitney, W. M. Miller, T. A. Wheaton

ABSTRACT. *Site–specific monitoring of citrus yield is important in understanding yield variability and its causes. A microcontroller–based system was designed to automatically monitor citrus yield harvested into individual tubs. The microcontroller was interfaced with a differential global positioning system (DGPS), a flash memory key, two limit switches, a buzzer, and a counter, which provided position information, storage, triggering, acknowledgement, and counting, respectively. The microcontroller system was mounted on a special truck (goat) that handles fruit and fruit tubs in the groves. The system was designed such that whenever the fruit was dumped into the truck bed, DGPS information was acquired and the counter and buzzer were triggered. The position information was then stored into a flash key and later downloaded to a personal computer for data analysis and mapping. This article details the design and evaluation of the citrus yield monitoring system. The evaluation phase showed that the system was able to detect the dumping events and store the DGPS locations, 100 and 98% of the time, respectively.*

Keywords. *Electronics, Instrumentation, GPS, GIS, Precision agriculture.*

Site–specific mapping of citrus yield is important in the identifying and understanding factors that cause spatial variability of yield over a given area. Tree size, age, health, spacing, and soil properties are some of the factors that cause yield variability (Whitney et al., 1998). For example, nematodes are known to affect certain areas within a block (Schueller et al., 1999). Unhealthy and young trees tend to have lower yield compared to healthy medium age trees. Similar problems exist for other tree crops (Righetti, 1997). A yield variability map would assist in the identification of such problems or situations. Because it would be possible to identify areas with varying yields, specific management strategies may be applied to those individual areas instead of uniformly to the whole block.

The design and development of yield monitors for different types of crops have been investigated as GPS technology has become commonplace. A real–time cotton flow sensor for yield mapping of cotton was developed (Wilkerson et al., 1994), utilizing an array of lights and a photodetector array. In laboratory tests, integrated sensor output showed good correlation with total cotton mass passing through the sensor ($r^2 = 0.93$). Wild et al. (1994) reported on a hay yield measurement system for round balers. When stationary, yields were measured with errors less than 2%. Campbell et al., (1994) described a potato yield sensing system. The sensor for the system was installed under the conveyor on a commercial potato digger. Hofman et al. (1995) described the use of a weighing conveyor system for measuring sugarbeet (*Beta vugaris* L.) yield. Vellidis et al. (2001) reported the peanut yield monitoring system. The yield monitor showed accuracy of approximately 1% on a field basis when using data collected during combine operation. Al–Mahasneh and Colvin (2000) constructed a commercial combine yield monitor for grain, which included a weighing system in the clean grain tank.

In the Florida citrus industry, most of the fruit is hand harvested and initially put in bags. The quantity of harvested fruit in the grove is tallied in 'field boxes,' which is a volume measurement. For processed fruit, the bags are emptied into small or large size tubs with a volume of approximately 0.56 m^3 (8 field boxes) and 0.7 m^3 (10 field boxes), respectively. Each tub is emptied into a fruit handling truck ('goat') with a hydraulically actuated loader boom (fig. 1). The 'goat' is also used to move empty tubs from one location where fruit has been harvested to another where the fruit is yet to be harvested. Depending on the size of the tubs, the 'goat' has a capacity of between 8 and 12 tubs (80 to 100 field boxes). When the 'goat' bed is full, the fruit is transported from the field and dumped into the semi–trailers having a capacity of about 500 field boxes of fruit. When the semi–trailer delivers fruit to the processing plant, the fruit is weighed as 'weight boxes' (e.g., one weight box of oranges = 40.9 kg). A field box is roughly equivalent to a weight box, but the field and weight box tallies on a semi–trailer load of fruit can often differ by greater than 5%.

Citrus yield monitoring systems have been under development for several years. The first yield monitor unit was developed by Geo–Focus (Gainesville, Fla.) (Whitney et al., 1998 and 1999; Miller and Whitney, 1999; Schueller et al.,

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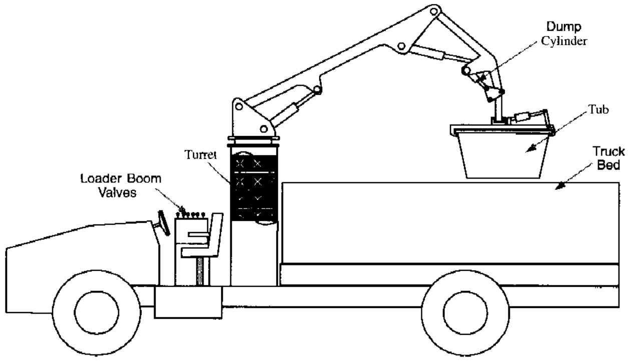

Figure 1. Schematic drawing of 'goat' vehicle with a hydraulic loader boom.

1999). The unit used a Lassen–SK8 low–power GPS board (Trimble Navigation, Sunnyvale, Calif.). The unit had a data logger that recorded a container location (latitude, longitude, and time) whenever the operator pushed the button. Schueller et al. (1999) noted that the system sometimes produced erroneous yield maps because the operator of the goat truck sometimes failed to push the button due to the rush of harvest or other reasons.

Another problem was that latitude and longitude readings had to be post–processed for differential correction. This problem of post–processing data for differential correction was solved by using a differential global positioning system (DGPS) (Whitney et al., 1999). A Trimble GPS/ DGPS antenna and Lassen–SK8 board were used to provide differentially corrected latitude and longitude readings. The position accuracy of the Trimble system was crosschecked using a Garmin GPS 12XL with a GPS 21 differential correction unit (Garmin Co., Olathe, Kans.) and a Rockwell Vision System (Rockwell Collins, Inc., Cedar Rapids, Iowa). The same Geo–Focus yield monitor was used.

To avoid the problem of the operator failing to push the button, an automatic triggering system was developed (Salehi et al., 2000). The system consisted of a Geo–Focus yield monitor, DGPS, two pressure switches, a position switch, and two timers. The pressure switches were used to detect load on the main boom lift cylinder and on the dump cylinder. The position switch was attached to the vertical turret that moved the hydraulic lift arm in and out of the truck bed, and it was used to detect if the lift arm was inside or outside the bed. The first timer was used for holding a switch closure for 0.2 s in order to record DGPS information while the second timer was used to prevent multiple DGPS triggering caused by re–dumping and slow dumping, a practice operators sometimes use to completely empty the fruit from the tubs.

However, test results of the automatic triggering system showed fewer records than those recorded manually by the operator (Salehi et al., 2000). The missed records were attributed to the adjustment of the delay timer, pressure switch settings, hardware connections, and weak DGPS signal reception. In addition, the system used the same Geo–Focus yield monitor, which was specifically designed for manual triggering. It was not feasible to program the microprocessor to incorporate program delays thereby replacing hardware such as the delay timer.

This article reports the development of a new yield monitor system that is designed specifically for automatic yield monitoring. The yield monitor used tub (field box) counting instead of a load cell (tub weighing) because harvesters are used to tallying field boxes or tubs. In addition, incorporating fruit weighing would be an added expense.

The main objective of this research was to design a microprocessor–based citrus yield monitoring system that could accommodate standard GPS signal (NMEA 0183 string) input and provide automatic data logging and feedback to the operator on event recording. The specific objectives were: (1) to design a yield monitoring system for the automatic yield monitoring of citrus using an automatic detection of citrus tub dumping method, (2) to evaluate the automatic yield monitoring system in a commercial harvesting environment.

Materials and Methods

Hardware Description

Figure 2 shows the schematic diagram of the yield monitor system. The system was comprised of a microcontroller, RS232 board, data key driver, data key, counter, buzzer, GPS antenna and receiver, and two limit switches. The microcontroller was a PK2110 type (Z–World, Davis, Calif.) having two serial ports, expansion port, digital inputs and outputs, analog inputs and outputs, and two relays. The RS–232 board was a Z–World XP8700 board with a full–duplex asynchronous port that supported 18 different baud rates from 50 to 38,400 bps. The data key driver was a Cyberdrive 232 serial reader/writer (Dynasys, Clearwater, Fla.) that could be operated continuously at RS–232 asynchronous speeds of up to 57,600 bps. The data keys were 8–Mbits flash memory keys (Dynasys, Clearwater, Fla.). The two limit switches were roller arm level (Omron Electronics LLC, Schaumburg, Ill.) and roller plunger (Matsushita Electric Works, Japan). An Ag132 DGPS antenna and receiver (Trimble, Sunnyvale, Calif.) were used to provide date, time, and differentially corrected latitude and longitude information. The Coast Guard Beacons provided RTCM differential correction signals.

The roller arm level limit switch was installed on the turret responsible for moving the loader boom outside and inside the bed (fig. 1). The roller arm limit switch was positioned such that when the loader boom was inside the bed the limit switch would be closed and vice versa. The roller plunger limit switch was installed just below the hydraulic valve lever of the dump cylinder such that the switch was closed during dumping and open when there was no dumping. Therefore, based on the two limit switches, the microcontroller was able

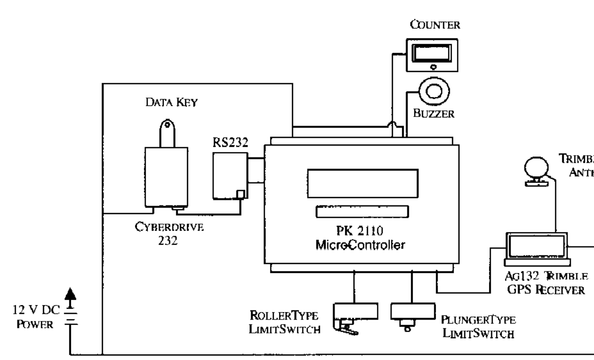

Figure 2. Schematic diagram of the automatic citrus yield monitor system.

to track movement of the loader boom inside and outside the bed and the dumping of the tubs.

The GPS unit was used to provide date, time, and position information whenever tubs were dumped into the truck bed. The data keys were used to store date, time, and the position information. Whenever tub dumping was detected by the microcontroller, the counter and the buzzer were triggered to inform the operator that the dumping event was detected and recorded. The counter and the buzzer were connected to the two relays on the microcontroller.

Software Description

Dynamic C software (Vers. 5.x, Rev. 2; Z–World, Davis, Calif.) was used to implement the yield monitor algorithm shown in figure 3 in the microcontroller. The flowchart starts with initialization of communication ports for the DGPS receiver and data key driver and by checking data key status. It is followed by detection of the dumping events. If there is dumping of fruit on the bed, the program acquires two National Marine Electronics Association standard sentences (NMEA–0183), namely GGA, containing DGPS fix data, and RMC, containing recommended minimum specific GPS/transit data (Trimble Precision Agricultural Systems, 1999).

A major portion of the program development involved the tub dump detection routine. At the start of the program or during data storage in the data key, the status of the loader boom is not known. In other words, the loader boom might be outside the bed or inside, dumping or not dumping. Therefore, the tub dump algorithm was implemented with two stages (fig. 3). The first part (stage) was used to determine the status of the loader boom and the second stage was used to track the loader boom movement and dumping.

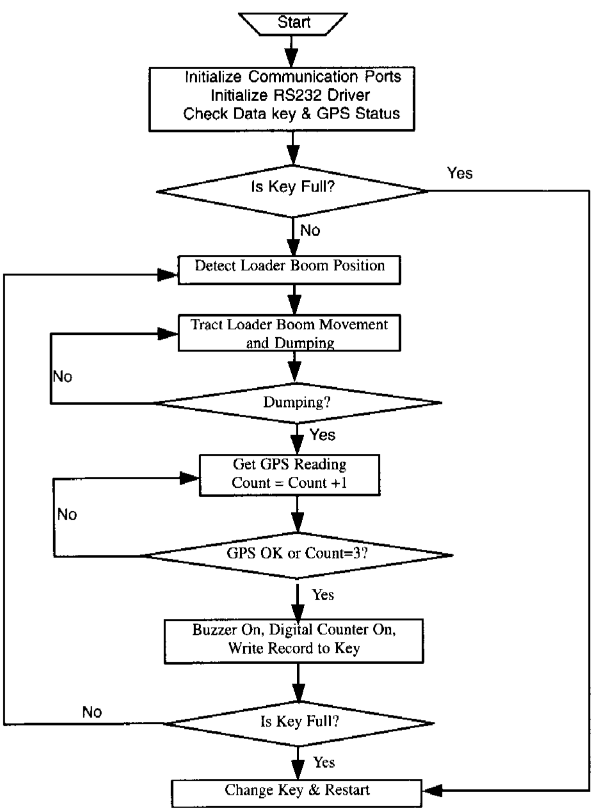

Figure 3. Algorithm for automatic citrus yield monitoring.

No manual initialization was needed because the system initialized itself on start–up.

Field Evaluation and Data Analysis

The yield monitor was installed on a 'goat' truck operated by Haines City Citrus Growers Association (Haines City, Fla.). The unit was tested in a commercial Valencia orange grove located at Lake Wales, Florida. A data key was inserted every morning before the start of work and taken out at the end of work. A special form was used to record the number of tubs dumped, counter reading, and number of records in the data keys. The evaluation was conducted between 20 March and 2 April 2001 with tubs that had a capacity of about 0.56 m^3 or eight field boxes.

Two types of data analysis were implemented. The first involved comparison of the number of tubs counted by the operator to the number of counts/records on the counter and in the data keys. The comparison was made with the assumption that operator's records were correct. The number of records on the counter at the end of each day was divided by the operator's count to obtain percent records (tub dump events) that the unit was able to detect. In addition, the number of records in the data keys was divided by that of the operator and the percentage was then computed. The aim was to quantify how many events were actually recorded.

In the second analysis, the collected data were used to create yield maps using ArcView® software (ESRI, Redlands, Calif.). Two types of yield maps were created and overlaid on a georeferenced aerial photograph. The first yield map showed points where the tubs were loaded and the second map showed an interpolated yield surface map. The density mapping of point features and inverse distance weighted least square interpolation method (Ripley, 1981) were used in generating the yield surface map.

Results and Discussion

Detection of Tub Dumping

Table 1 shows the tub dumping counts on days 1, 5, 6, and 7 when there were identifiable system problems. There were differences in tub counts between the operator, the counter, and the data key. The differences on day 1 were due to the settings of the elevation masks in the DGPS unit. A record was not logged unless new GPS information was available. For continuous operation especially when operating near a tree canopy, elevation masks need to be low (Trimble, 1999). The initial setting was too high (12°) such that some satellites were omitted when positions were computed. The value of the elevation masks was lowered to 5°. In addition, the position dilution of precision was originally three, but was increased to six. Both a lower elevation mask and a reduced position dilution of precision enhanced the probability that a new GPS record is available. Submeter accuracy was not considered important in citrus yield monitoring since one tub represents fruit from an area ranging from 0.005 to 0.02 ha depending on yield.

The lower percent of data key records on days 5, 6, and 7 was due to improper wiring of the power supplied to the data key driver. The 12–V power source was not properly installed and therefore sometimes no power was supplied to the data key. It caused the battery power inside the data key driver to be drained fast and failed to save data into the data key. The

Table 1. Tub dumping counts when system had identifiable problems.

Day	Operator's Count	Counter Reading		Data Key Records	
		Tubs	%[a]	Tubs	%[b]
1	130	130	100	124	95
5	115	114	99	62	54
6	145	145	100	134	92
7	146	146	100	111	76

[a] Percent of tubs recorded on the counter compared to the operator's count.
[b] Percent of tubs recorded in the key compared to the operator's count.

problem was later corrected by connecting the driver to a 12–V source and power/charger for the battery unit.

Table 2 shows the tub dumping counts after the system had identifiable problems corrected. There was good agreement of the data on days 2, 3, and 4 after DGPS settings were modified and on days 8, 9, and 10 after solving the wiring problem. The differences between operator's count and datakey and counter records may have been due to operator's error. Besides driving the vehicle and manipulating several levers to operate the tub dumping system, the operator had to manually record or credit the harvester who had harvested the fruit in each tub. The operator's counts were equal to/or greater than the counter and data key counts.

Therefore, the microcontroller and the implemented algorithm were able to detect the tub dumping events (table 2). In other words, the operator's records and counter readings could be used to counter check records in the data key (table 1) while counter and datakey records can be used to counter check the operator's count.

Compared to the previous citrus yield monitors that were developed or modified, this system was able to automatically detect the dumping of the tubs with fewer components. For example, this system did not use hardware timers and pressure transducers compared to the previous yield monitors used in the past (Salehi et al., 2000). Therefore, this system was simple and much cheaper and avoids operator error because it does not require a manual trigger to record the dumping event.

Table 2. Tub dumping counts after system had identifiable problems corrected.

Day	Operator's Count	Counter Reading		Data Key Records	
		Tubs	%[a]	Tubs	%[b]
2	137	137	100	137	100
3	73	72	98	72	98
4	108	108	100	108	100
8	128	126	98	126	98
9	144	144	100	144	100
10	68	68	100	68	100

[a] Percent of tubs recorded on the counter compared to the operator's count.
[b] Percent of tubs recorded in the key compared to the operator's count.

Yield Mapping

The NMEA sentences stored in the data keys were downloaded into a personal computer and used to create yield maps. Figure 4 shows a map of tub locations overlaid on a georeferenced aerial photograph. The areas of high concentration of the tubs correspond to areas with high yield whereas areas of low concentration correspond to areas with low yield. Another map (fig. 5) was generated by surface interpolation of the tub locations in figure 4. The areas of high and low production are clearly shown. The map is presented in the units of tons per hectare by assuming a constant of 328 kg of fruit per tub/container, which is a standard conversion for oranges in Florida citrus. Most areas show a yield of less than 24 t/ha while the state of Florida average is about 35 t/ha for Valencia oranges. In general, the east (right) side of the grove shows lower yields compared to the west (left) side. The data showing subpar yields can assist the grower in developing site–specific management strategies for either increasing the yields on those areas or abandoning growing citrus in areas that are not profitable.

Conclusion

An automatic citrus yield monitoring system was designed, developed, and implemented to acquire position

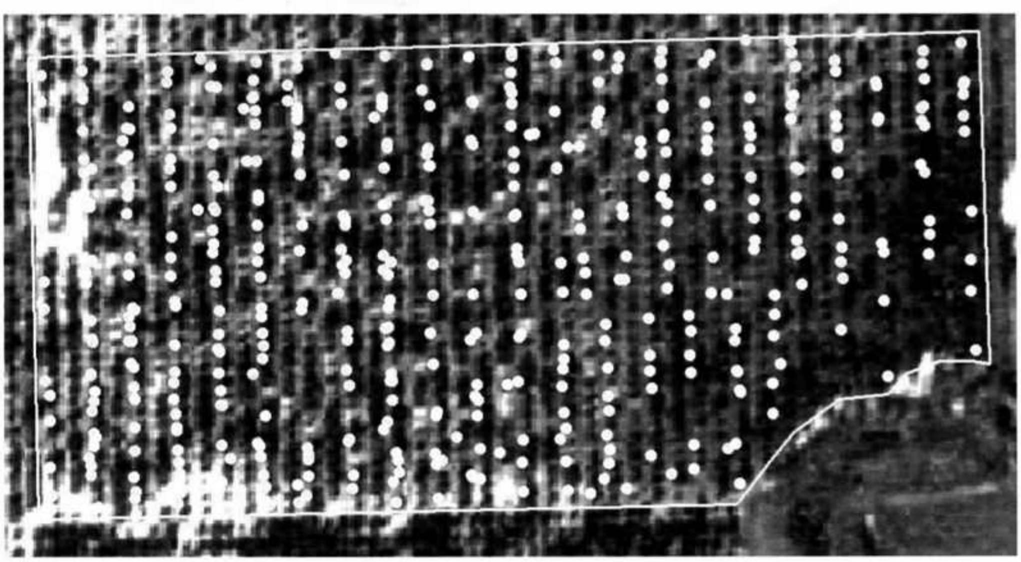

Figure 4. Geo–referenced aerial photograph overlaid with fruit tub locations in a 5–ha grove.

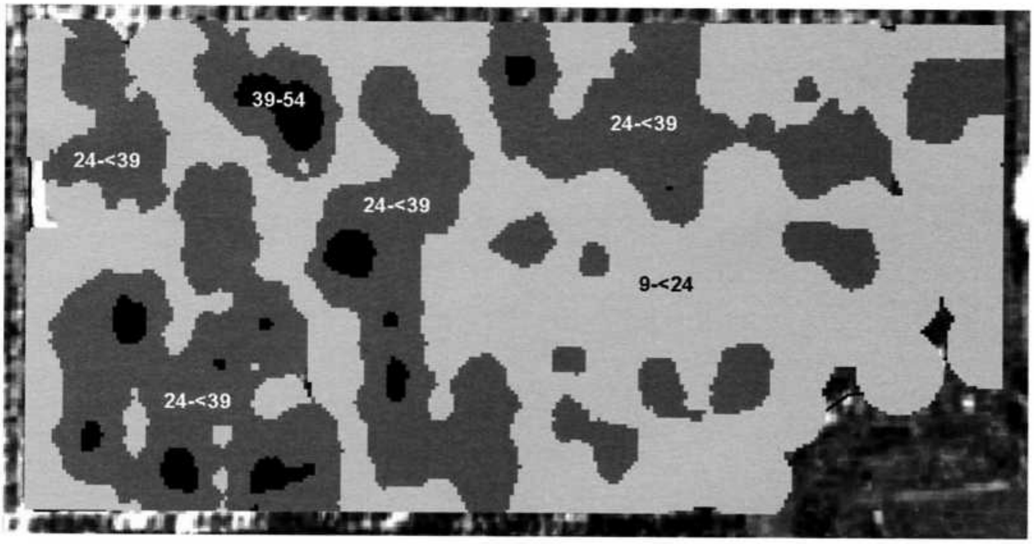

Figure 5. Surface interpolation yield map of a 5–ha grove in t/ha from fruit tub locations shown in figure 4 overlaid on a geo–referenced aerial photograph.

information as the citrus fruit was dumped from tubs into a 'goat' truck. In the evaluation stage, the system was able to detect the dumping events and store DGPS positions in the datakey at a 100 and 98% success rate. The position information was used to create an interpolated yield map showing yield variations within a citrus block. Therefore, the grower can use the information in developing site–specific management strategies that can be applied to those areas instead of uniform application to the whole block.

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