Sensor Comparison for Yield Monitoring Systems of Small-Sized Potato **Harvesters**

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Abstract. *Yield monitoring of potato in real time during harvesting would be useful for farmers, providing instant yield and income information. In the study, potentials of candidate sensors were evaluated with different yield measurement techniques for yield monitoring system of small-sized potato harvesters. Mass-based (i.e., load cell) and volume-based (i.e., CCD camera) sensors were selected and tested under laboratory conditions. For mass-based sensing, an impact plate instrumented with load cells was placed so that the potatoes discharged from the transportation part were contacted before they fell down to the collection part. Load cell signals due to the plate bending by the impact force were calibrated to the mass of the potatoes. Effects of potato dropping height on load cell was investigated for single potato and multiple potatoes. For volume-based sensing, a CCD camera was installed above the transportation part so that the top and side images of the potatoes were captured. Area and volume were obtained from the original images and calibrated to the mass of potatoes. The calibration tests of potato showed linear calibrations with* R^2 *of 0.98 for potatoes dropped from a height of 30 cm for the mass-based and 0.37 for volume-based approaches. This study showed potentials of candidate sensors for yield monitoring of potato yield monitoring system. Further study would be necessary to investigate the effects of vibration and harvester inclination for field application.*

Keywords. *Precision agriculture, Load-cell, CCD camera, Yield monitoring, Potato harvester.*

Introduction

Yield monitoring is one of the essential components of precision agriculture provides instant yield and income information to the producers (Thomas et al., 1999; Chung et al., 2016). Measurement of potato yield is a major interest of producers, therefore, commercial yield monitoring systems have been developed more recently for grains and several other crops, however, very few yield monitoring systems are available for small-sized potato fields.

A yield monitoring system mainly consists of mass or volumetric flow sensor. A number of researches have been reported for sensing techniques of potato yield. Yield monitors based on mass flow have been developed for the measurement of potato yield (Demmel and Auernhammer, 1999). Image-based yield monitoring systems were tested on laboratory condition for estimating weight of the potatoes (Persson et al., 2004). Weighing cell in belt conveyors (Campbell et al., 1994), bounce plate (Ehlert, 2000) have been reported for sensing potato yield. A machine vision system on the conveyor of a harvester was developed to estimate the volume of individual potato tubers by Hofstee and Molema (2002, 2003). An impact-based sensor has been used by Tokunaga and Shoji (2006) to determine the individual weight of potato tubers.

Load cells are used for monitoring crop yield with commercial sensors as they are adaptable to a variety of working conditions. An impact-based yield sensor comprising of load cells was developed for measuring the weight of individual onion bulbs through the impulse received by the sensor and 30-mm cushion with impact plate resulted in a relative error of less than 2.0% (Qarallah et al., 2008). Shoji et al., (2002) developed an impact-based for grain yield sensor; a continuous mass flow-type a load/yield monitor equipped with load cells was developed for tomato harvester (Pelletier and Upadhyaya, 1999). A mass-flow sensor based peanut yield monitor was developed and showed strong correlation with the harvested load weight with R^2 values ranged from 0.89 to 0.96 (Thomasson et al., 2006). An image-based yield monitoring system was developed and tested on stationary sweetpotatoes in the laboratory and weights were found highly correlated (R^2 = 0.96) with actual weights for sweetpotatoes (Gogineni et al., 2002).

Numerous factors affect during yield estimation and mapping in yield monitoring system. Proper installation, calibration, and operation of yield sensors of the yield monitoring system is very important for accurate yield estimation and mapping. Selection of the best mounting configuration of yield sensor is also essential for functioning under different working conditions. Therefore, proper data acquisition hardware and software were tested under laboratory conditions for developing a potato yield monitoring system.

Mechanization of upland crop production and smart farm are popular trends in Korea, especially for small sized field plots. Potato is one of the crops that the mechanization needs to be improved. Based on the farmers' need, tractor-mounted type harvesters that can dig out potatoes from the soil, separate soils and crop residual materials from the potatoes and collect the separated potatoes in a bag are under development. Yield monitoring sensors for measuring potato yield in real time during harvesting would be useful for measuring, spatially referencing, and yield mapping.

Therefore, the objective of this research was to develop the initial concepts of a potato yield monitoring systems suitable for small-sized potato fields by comparing the potentials of candidate sensors through laboratory tests.

Materials and Methods

Potato Yield Monitoring System

The major components of the mass-based (left) and volume-based (right) yield monitoring system are shown in Figure 1.

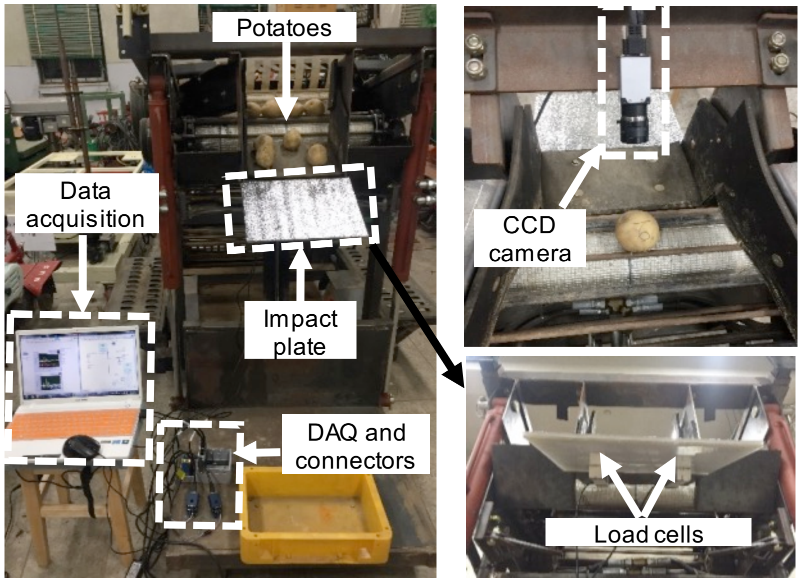
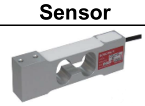
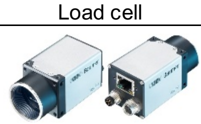


Fig 1. Test bench of the potato yield monitoring system showing arrangement and locations of the sensors.

The mass-based yield monitoring sensor consists of impact-plate with two load cells (model: OBU-10; Bongshin Loadcell Co., Ltd., Seongnam, Korea) for determining the weight of the potatoes. The impact plate was cushioned with polyurethane foam for absorbing the shocks. The load-cells were connected to a 4-channel module (model: NI 9237, National Instruments, USA) via NI 9949 screw-terminal connector. A 4-channel data logger (model: NI cDAQ-9174; National Instruments, USA) was used to collect the sensor output. A LabVIEW software program (version 2015; National instrument; Austin, Texas, USA) was applied to collect sensor output.

For volume-based yield monitoring system, a CCD camera (model: VLG-12M, Baumer, Germany) with 1288 × 960 resolution was employed for acquiring images of potatoes from the conveyor belt without extra illumination, flash or covering. The camera had a 1/3 in. CCD chip and 3.75 *3.75 µm pixel images were available as three channel images in the RGB color space. The specification of the CCD camera is shown in Table 1.

Table 1. Specifications of the sensor modules.

Sensor	Specifications
 Load cell	Model: OBU-10; Bongshin Loadcell Co., Ltd., Seongnam, Korea
	Rated capacity: 10 kg
	Rated power: 2.0 mV/V
	Input/output register: 410/350 Ohms
 CCD camera	Model: VLG-12M; Baumer, Germany
	Type: 1/3” progressive scan CCD, global shutter
	Resolution: 1288 × 960 px
	Pixel size: 3.75 × 3.75 µm
	Image formats, frame rate max.: Full Frame, 1288 × 960 px, max. 42,0 fps

Mass-based Yield Sensing

Impact Plate and Cushion

The impact plate with polyurethane foam was placed to the horizontal plane beneath the output end of the conveyor. The plate comprised of two load cells instrumented with an acrylic plate (300 mm × 180 mm × 3 mm) affixed with a polyurethane cushion of 10 mm thickness. The load cells were placed at a distance of 145 mm supported the impact plate (Figure 2).

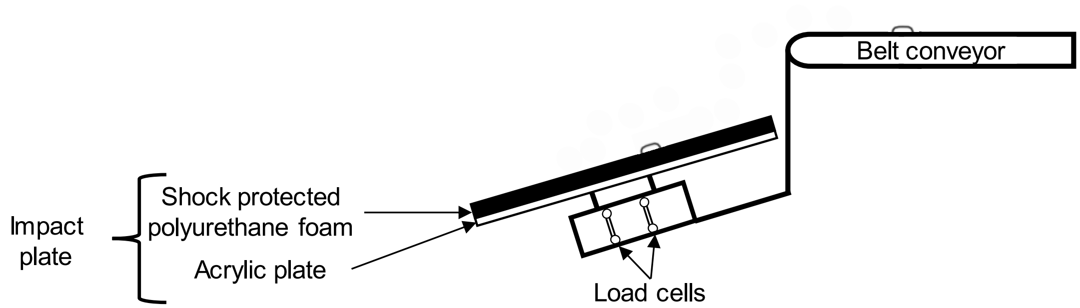


Fig 2. Arrangement of the impact plate and load cells for sensing weight of potatoes.

Volume-based Yield Sensing

CCD Camera and Image Acquisition

The main components of the image-based data acquisition systems in shown in Figure 3. The CCD camera used for acquiring the potato images had a chip of 1/3 in with resolution of 1288 horizontal × 960 vertical, progressive scanning, continuous video outputs. A shutter rate of 1/50 s was selected as ideal for the system considering the light conditions, and the lens aperture was adjusted for good exposure. Baumer GAPI 2.6 Camera Explorer was connected to PC for acquiring the potato images.

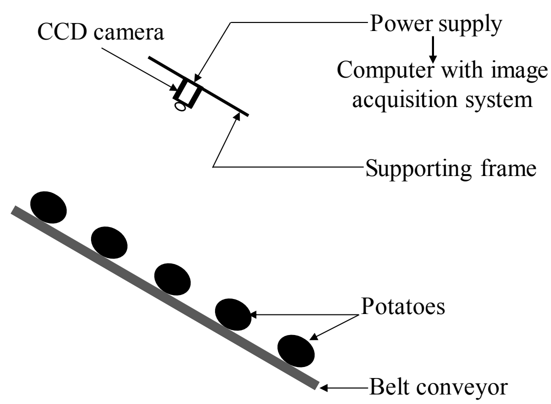


Fig 3. Arrangement of the volume based yield sensing of potatoes.

Calibration and Data Analysis

The arrangement of the load cells, potatoes, the thickness of the cushion, and the potato falling height were taken as the experimental factors. Based on the impact of the potato, the signals were recorded at 1 kHz. 15 potatoes of different sizes were considered for the basic tests. Potatoes at a height of 0, 10, 20, 30, and 40 cm were tested for single potato and multiple potato conditions. Coefficient of determination (R^2) were calculated during calibration.

Images of the potatoes were acquired and processed for extracting the features. Acquired images were processed to binary images overlying white area in order to calculate the number of white pixels. A linear regression model was used to calibrate the weight of potato with total number of white pixels from the potato images.

Results and Discussion

Yield Measurement and Calibration with Load Cell

Impact received by the load cells from potatoes dropped from different heights were converted to weight of individual potato, then weight of potato was calibrated. Potatoes dropped from heights at 0, 10, and 20 cm showed similar results with R^2 value of 0.97. Figure 4 shows the relationships between the calibrated weight and the actual weight of potatoes fallen from different height.

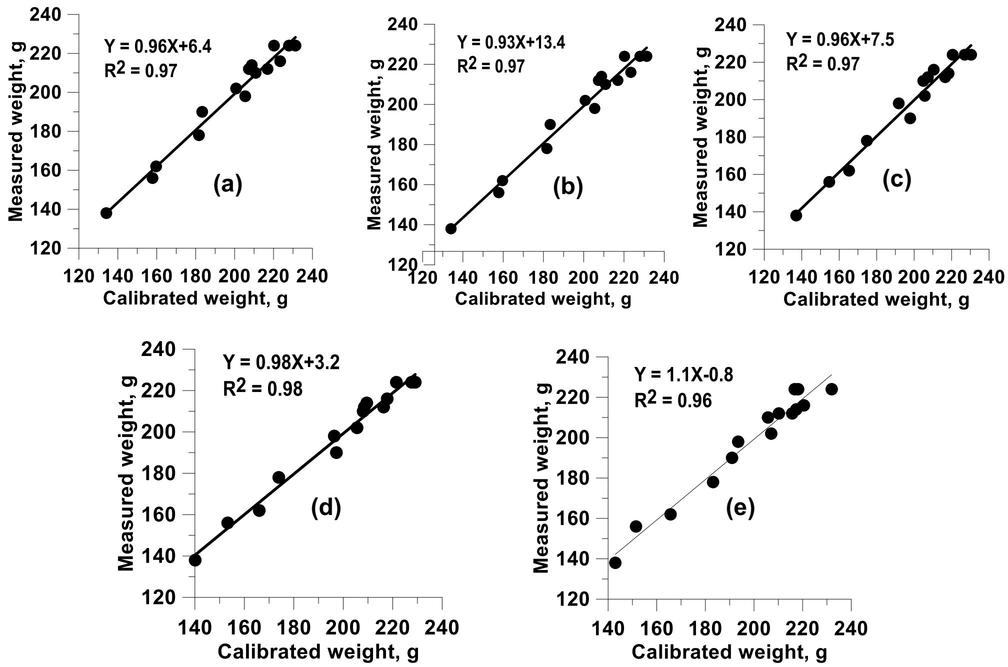


Fig 4. Sensor output by potato dropping height between the impact plate and the potato at a distance of 0 cm (a), 10 cm (b), 20 cm (c), 30 cm (d), and 40 cm (e).

Yield Measurement and Calibration with CCD Camera

A binary image process was conducted using gray scale images of potatoes for calibrating weight of the potatoes. Acquired images were analyzed to calculate the number of pixels in the potato area as shown in Figure 5.

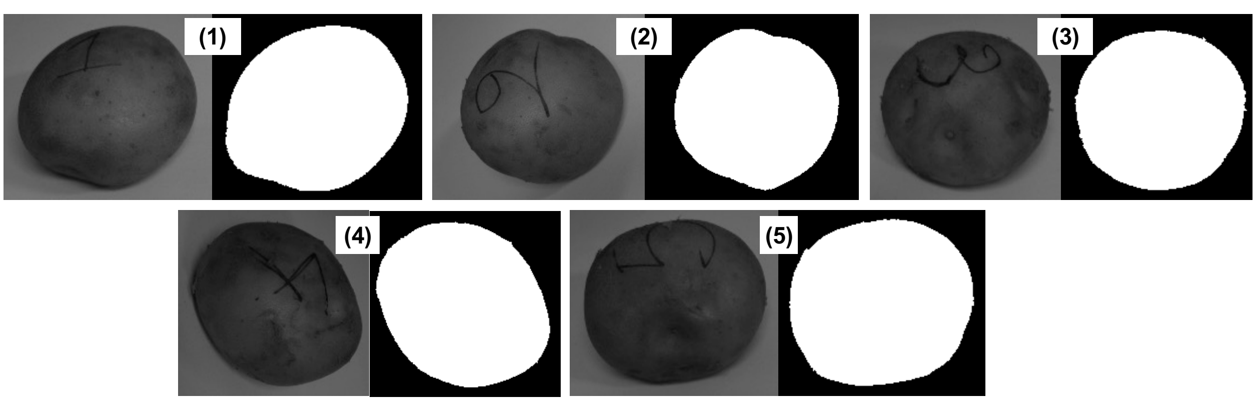


Fig 5. Examples showing image processing of each potato: original image (left) and binary image (right).

The cross-sectional area of the potatoes under CCD camera was measured for each of the potatoes, and a function describing the weight from the amount of the white pixels was calibrated. An example of this is shown in Figure 6 and could be found in the equation with correlation co-efficient (R^2) of 0.37.

$$Y = 0.002*X - 38.5 \tag{1}$$

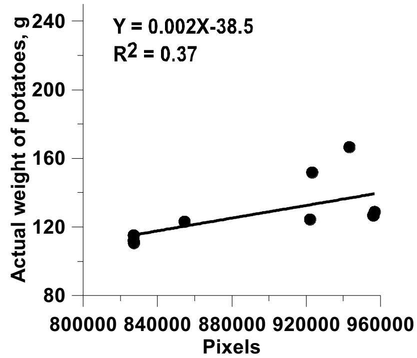


Fig 6. Calibration curve for potato yield sensing based on actual weight and pixel-value analysis.

Performance Comparison of the Yield Sensors

In order to determine the most favorable impact plate and CCD camera arrangements, calibration results with coefficient of determination (R^2) values were considered for performance comparison. Calibration tests results showed that that potato yield could be monitored by the load cell and the CCD camera.

The load cell calibration test results between impact load received by the load cell and actual weight of potato showed linear relationships. Calibration results from potato dropping heights at 0, 10, and 20 cm showed similar results with R^2 value of 0.97. But the load cell at a height of 30 cm resulted linear calibration with higher R^2 value of 0.98.

A linear relationship was obtained from the calibration results between white pixel count and actual weight of the potatoes with R^2 value of 0.37. This image-based yield sensing approach can be used to measure the weight of potatoes but less effective compared to the mass based measurement. However, the results could be different at field conditions due to the vibration, slope, and the operation speed of potato harvesters.

Conclusion

Among precision agriculture technologies, yield monitoring technology is in an increasing trend in some developed and developing countries. Aiming the potato yield monitoring system, basic laboratory tests were carried out to compare the candidate sensors in order to determine the appropriate position and measurement techniques of the sensors for yield sensing of potatoes.

An impact plate system with load cells was developed and tested under laboratory conditions to determine the weight of potatoes. Different potato dropping height from the conveyor outlet to impact plate were tested for determining appropriate position of the impact plate.

An image-based potato yield sensing system was tested for calibrating the weight of each potato. A CCD camera was used to acquire the potato images and image processing techniques were applied to estimate the number of pixels of the potato from the binary images. A linear regression model was used to calibrate the weight of potato.

This study showed potentials of load cell and CCD camera based yield monitoring system for sensing potato yields. Further studies are necessary to investigate the effects of vibration and harvester inclination under field conditions.

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