Potential of impact-based weight sensing of individual Chinese cabbage for real-time yield monitoring

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Abstract. Yield monitoring is one of the basic components of precision agriculture. It provides information on the spatial variability of yield in the field. The objective of this study was to estimate the weight of Chinese cabbage through impact force measurements using a weighing sensor. The sensor was installed to receive the impact of Cabbage as it dropped off an inclined conveyor. The investigated experimental variables were fall height, plate angle to the horizontal, and conveyor speed. The load cell was calibrated, with an R² value of 0.96. The mean absolute percentage error (MAPE), root-mean-square error (RMSE), and correlation coefficient (R²) were the statistical indicators used to describe the accuracy of the estimates. The fall height had little effect on the precision of the yield sensor. The least sensing precision was 18.75%, observed at an angle of 30° with a conveyor speed of 0.05 m s⁻¹. The MAPE for cabbage weights were < 3% at 40° and 0.2 m s⁻¹ for both fall heights. The experiments showed the potential of measuring individual cabbage weights for yield estimation.

1. Introduction
Yield monitoring is an essential part of precision agriculture for providing spatial variability of crop yield [1] and helps to improve management practices. Recent studies have shown a rising trend in the development of both mass-based and volume-based yield-monitoring approaches. For mass-based monitoring, direct weight measurement of crops is used using either mass flow rate sensors, batch weighing, or cumulative weighing [2]. Based on the mass flow rate, [3] developed a continuous weigh-tomato yield monitor for tomatoes. A weighing plate was also developed [4] to monitor sugarcane yield. In all cases, load cells were used as the impact-type mass flow sensors.

However, one of the challenges of cumulative or batch weighing systems is to estimate the weight of foreign material picked up by harvesters [5]. Therefore, individual weight measurement especially for high-value crops is necessary. An impact-type yield monitor for measuring the mass of individual onion bulbs was developed by [6]. The results suggested that individual weight measurements were aimed at enhancing the market value of the crops. Volume-based techniques have also been used for yield estimation using image processing through counting individual crops across the field [7]. Using machine vision, [8] developed a system for counting individual citrus fruits.
Mechanization of the upland crop production is a popular trend in many countries, and Chinese cabbage is one of the crops that the mechanization needs to be improved. A real-time yield monitoring system is useful for measuring, spatially referencing, and yield mapping during crop harvesting. Although several studies were conducted to monitor the real-time yield for different crops (i.e., potato, tomato, rice, wheat, and corn), a Chinese cabbage yield monitoring system is under development in this study. The objective of this study was to estimate the individual weight of Chinese cabbage considering the fall height, plate angle to the horizontal, and conveyor speed, using a weighing sensor.

2. Materials and methods

2.1. Overall system layout
Chinese cabbage harvesters/collectors consist of a cabbage transportation/conveying part which constitutes power transmission, conveyor, and a cabbage outlet unit [9]. For this study, the conveyor, and the cabbage outlet sections were considered. During field operations, the cabbage is fed onto the conveyor which moves the cabbages in the upward direction to the outlet section at a given speed. In the study, the outlet section was chosen as the most appropriate part to setup an impact based system for weighing individual cabbages falling from the conveyor. Figure 1 shows the overall system layout of yield monitoring system for Chinese cabbage.

![Figure 1](image-url)

**Figure 1.** Conveyor and outlet sections of the cabbage collector: movement and direction of cabbage from inlet to outlet section (1-5); Chinese cabbage (a): conveyor (b); frame support(c); impact plate (d); collection bucket (e).

2.2. Test bench construction

2.2.1. The overall structure of the test bench. The test bench as shown in Figure 2 consists of an inclined conveyor, a support frame and an impact plate which is constituted of a load cell, an acrylic plate and polyurethane foam. The frame was constructed from 40mm x 40mm aluminium profiles. The impact plate was attached to the frame using adjustable joints to allow movement of the plate through different angles. It was attached at the outlet end of the conveyor system to receive the impact of cabbage as it fell off the inclined conveyor system.
2.2.2. Sensing approach. A rectangular load cell supported by an acrylic impact plate was used in the experiments. The sensitivity of the load cell was $2\text{mV/V}$ at a recommended excitation voltage of 10V. The signals upon impact were recorded at a sampling rate of 1 kHz using an NI DAQ 9237 (National instrument, Texas, USA) as shown in Table 1.

Table 1. Specifications of components used for individual cabbage weight measurement.

| Item             | Component               | Specification                                      |
|------------------|-------------------------|----------------------------------------------------|
| Sensing          | Load cell               | Model: CAS BCL-10L                                  |
|                  |                         | Range: (0-10)kg                                    |
|                  |                         | Rated output: 2.0mV                                 |
|                  |                         | Excitation voltage: 10V                            |
|                  |                         | Resolution: $\leq$4000                             |
|                  |                         | Type: Single - type                                 |
|                  |                         | Country of origin: Australia                       |
|                  |                         | Platform size: 300 X 300                            |
|                  |                         | Combined Error: 0.025%                             |
| Data acquisition | National instrument, USA| Model: NI 9237                                      |
|                  |                         | Channels:4, 50KS/s                                 |
|                  |                         | Resolution: 24bit                                  |
|                  |                         | Operating temp: -40°C to 70°C                      |
|                  |                         | Connectivity options: RJ50 or D-SUB                 |
## 2.3. Experimental plan

### 2.3.1. Conveyor speed

A group of 9 Chinese cabbages with a weight between 530g to 875g were selected for the preliminary experiments. The cabbages were purchased from the local market and selected randomly, irrespective of a particular cultivar. They were weighed first and then loaded onto a conveyor 1700mm x 500mm, designed specifically for these experiments and moving across a speed range of 0.02m/s to 0.24 m/s, as specified by the manufacturer (Hyundai agriculture, Iksan, Jeonju, South Korea), with conveyor speed considered an experimental variable.

### 2.3.2. Impact plate angle to the horizontal

The impact plate of 300\(\times\)300\(\times\)5 mm is shown in Figure 3, which is comprised of an acrylic plate, polyurethane cushion and a load cell. It was placed at three different angles (\(\theta\)) of 30°, 40°, and 50° to the horizontal at the output end of the conveyor. The angles were selected to avoid double impacts because it was assumed Chinese cabbage has a coefficient of restitution of 1. A polyurethane cushion (300 x 300 x 10 mm) was placed on the top of the acrylic plate to protect the load cells from damage.

### 2.3.3. Fall height

The horizontal distance (\(h_d\)) from the conveyor output to the impact plate was maintained constant at 300mm whereas two different vertical heights (\(v_d\)), 120mm, and 160mm [6] were considered as experimental variables and categorized as low and high, respectively. The heights were selected to reduce the possibility of damage to the load cells from the cabbage fall impact.

![Figure 3. Experimental variables considered during the experiments.](image)

### 2.3.4. Statistical evaluation of cabbage weight measurement

The load cell was calibrated with five known weights and a calibration curve was used to estimate the weight during real-time experiments. Statistical indicators were selected to describe the accuracy of the estimates. Performance was checked using mean absolute percentage error (MAPE) and root-mean-square error (RMSE) as shown by Equations (1–2).

\[
RMSE = \frac{\sum_{i=1}^{n} (Y_i - X_i)^2}{n} \tag{1}
\]

\[
MAPE = \frac{1}{RMSE} \tag{2}
\]

Where, \(n\) is the number of data, \(Y_i\) is the predicted weight of cabbage, and \(X_i\) is the actual mass measurement.
3. Results and discussion

3.1. Performance of the load cell calibration
A linear relation was used to calibrate the load cells. First, different numbers of Cabbage samples were used to calibrate the single point load cell. The samples ranged from 1 to 5 with a weighting range from 0.5 kg to 9 kg. Consistent results were received with a sample of 5 for a whole range of the load cell output (0 kg - 10 kg). During the calibration, the cabbages were measured with an electronic digital scale and their weights were recorded. Then, they were measured using the load cell and the resultant voltage in mV was recorded. The measurements were completed with three replications to reduce errors as shown in Table 2. A calibration curve as shown in Figure 4 was generated and used as the baseline to estimate weights in the real-time experiments. The calibration tests resulted in a slope of 2.3 and a coefficient of determination (R²), of 0.96.

Table 2. Known weights used for load cell calibration and resultant output voltages.

| Known weight (kg) | Output voltage(mV)     |
|-------------------|------------------------|
| 1.02              | 1.7, 1.8, 1.8          |
| 3.04              | 7.7, 7.8, 7.7          |
| 5.05              | 13.6, 13.4, 13.8       |
| 6.90              | 17.1, 17.7, 17.9       |
| 8.99              | 19.9, 19.3, 19.9       |

![Figure 4](image-url)  

**Figure 4.** A calibration curve with different known weights.

3.2. Weight calculation affected by experimental conditions
As part of ongoing research, only four cabbage samples were selected to test the performance of the calibration curve to predict weight measurements. Overall, estimated weight measurements were slightly higher than the actual weight of cabbage. This could be due to the extended vibrations of the plate upon impact and noise from the surrounding environment. Various performance indicators were used to determine the best mass estimates and the results were summarized in Table 3 based on the fall heights consideration. The mass estimated at conveyor speeds of 0.05 ms⁻¹, and 0.1 ms⁻¹, at an impact
plate angle of 30° were lower than the actual. This could be attributed to the low impact force from the cabbages.

Figures 5 (a and b) shows the measured and predicted weights of cabbages using the load cells with a conveyor speed of 0.05 m s⁻¹ and 0.2 m s⁻¹, respectively and the impact plate angle of 30° and 40° respectively for a fall height of 12 cm. Similarly, Figure 5 (c, d) shows the results at a falling height of 16 cm. It demonstrated that the load cell measurement was more precise at 40° in both cases with a mean average percentage error of 1.57% and 1.58%, respectively, and with an accuracy of 95% and 99%, respectively. The corresponding values at 30° were 18.75% and 17.62%, respectively, and an accuracy of 88% and 93% respectively. The linear relationship between predicted and measured weights was higher at high speeds than at low speeds. The experiments were carried out at low fall heights and this could have increased the impact force with which cabbage hit the impact plate in Figures 5 (b and c) and led to partial double impacts at low speeds. Furthermore, it was also observed that with the increase of speed, the signals were more susceptible to noise. Therefore, proper signal conditioning methods with frequent calibration of the load cells are required to ensure more accurate and consistent results. Individual weight measurements of onions using load cells were reported with high accuracy results, with errors of ± 5% [6]. The observed accuracy was more than 95%, for all conducted tests. Other previous research focused on the batch weighing of crops for weight measurements.

Table 3. Performance indices under the investigated variables, speed (ms⁻¹), plate angle (θ) and fall height (cm).

| Conveyor speed(ms⁻¹) | Fall heights(cm) | Plate angles(°) | MAPE (%) | RMSE (g) |
|----------------------|------------------|----------------|----------|---------|
| 0.05                 | 12               | 30             | 18.75    | 126.32  |
|                      |                  | 40             | 12.7     | 82.46   |
|                      |                  | 50             | 12.60    | 81.09   |
|                      | 16               | 30             | 17.61    | 134.38  |
|                      |                  | 40             | 12.83    | 82.50   |
|                      |                  | 50             | 12.12    | 78.82   |
| 0.2                  | 12               | 30             | 3.34     | 23.18   |
|                      |                  | 40             | 1.55     | 10.61   |
|                      |                  | 50             | 1.62     | 10.56   |
|                      | 16               | 30             | 3.41     | 23.58   |
|                      |                  | 40             | 1.58     | 10.74   |
|                      |                  | 50             | 0.91     | 6.12    |
Figure 5. Predicted and measured weights at 0.05 m$^s^{-1}$, 30$^\circ$ (a, c), and 0.2 m$^s^{-1}$, 40$^\circ$ (b, d); 12 cm fall height (a, b); 16 cm fall height (c, d).

4. Conclusions
In this paper, mass estimation for individual Chinese cabbage using a single load cell was presented at different fall heights, conveyor speeds, and different impact plate angles. We investigated different variables to find out the combination that would give a better mass estimation of Chinese cabbage. From observation, when the sample number is increased, the calibration accuracy (<2% error) could be achieved. The load cells are sensitive to measurement conditions. Therefore, an appropriate signal processing technique would improve the accuracy of the results.

The presented system could be useful to monitor the yield of Chinese cabbage during the harvesting in field conditions. In future, we will consider different cabbage orientations, fall height, and impact plate angle to improve the system for better use for different cabbage cultivars with variable conditions.

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