Design of a laboratory-scale sugarcane weighing system

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Abstract. Recently, sugarcane harvesters have been increasingly used in sugarcane harvesting. Loading trucks were traveling along the harvesters to collect the harvested cane billets. Since cane harvesters are expensive machines, there is an idea of collaborative farming by combining multiple fields from different owners to reduce operating costs and time. However, it is difficult to fairly classify yields from different fields. Site-specific yield monitoring system is not common in typical harvesters. Farmers only know the weight on each truck without its collecting location when selling the sugarcane to the factory. This research was the feasibility study to develop a hydraulic weighing system in laboratory scale for further applying to the side-tipping loading trucks. A low-cost hydraulic weighing system was fabricated. A microcontroller was used to read signals from pressure and gyroscopic sensors and then to calculate the applied load. Accuracy and precision of the system were examined. The coefficient of determination ($R^2$) of the relationship between the actual and determined loads was 0.978. The standard error of prediction (SEP) of the system was 2.348 kg. The results show that there was feasibility to apply the system on farm scale; however, further study with a larger scale should be conducted.

1. Introduction

Sugarcane is one of the economic crops in Thailand who is the 4th rank of sugar exporters in the world. Thai government has promoted sugarcane production since sugarcane is the major crop in sugar and ethanol industries. In 2018, the sugarcane planting area was 11,188,802 rai (1.79 million ha), produced 131,717,042 tons of the raw sugarcane [1]. Due to the labor shortage, farmers usually burn sugarcane fields to get rid of residuals before harvesting to reduce harvesting time and labors. Nutrients in the soil would be simultaneously burned with the residuals. Furthermore, smoke from the burning causes PM2.5 pollution, which affects health problems, including the risk of cancer [2].

Using of sugarcane harvester is a recommended option that can help solving the labor shortage problem. Sugarcane harvesters are very effective when working in the fields with long row length. Farmers who want to use harvesting machine have to prepare their field to be suitable for the machine in respect of surface roughness and length of the field. Averaged time that sugarcane harvester used for turning is approximately 2.34 minute [3]. To avoid this time-consuming activity, it was suggested that the row length should be longer than 140 meters. The smaller field causes more turns at the headlands, which limits the capacity and efficiency of the sugarcane harvesters. Ukrit [4] pointed that large-scale farms have the average cost lower than that of the small farms.

In the current harvesting process, the sugarcane harvester cuts and chops the cane stalk into billets. The billets are then accumulated and fed on the elevator conveyor. A loading truck is required to travel along with the harvester to collect the billets from the end of the elevator. Since the trucks used in the process are typical trucks designed for transportation purpose, there were many concerns about soil
compaction issue. In order to reduce this soil compaction problem caused by the weight of truck traffic on the sugarcane plot, the side-tipping loading trucks have been introduced. The side-tipping loading trucks are designed for travelling on the field, not the paved road. They use tires that require much lower inflation pressure causing a better weight distribution over the field. Therefore, the side-tipping loading trucks cause less affect in soil compaction than that by the transportation trucks.

Recently, Thai government has introduced large-scale farming policy encouraging farmers to gather their farms to work together as a collaborative farm. Sugarcane farms have been expected join the collaborative farm by pooling the adjacent fields into one large plot. In this scheme, farmers could share resources. The harvesters and other machines could work efficiently in larger fields. Operational time and cost would be reduced significantly.

Since the variation at different part of the field is typically high, it is not easy to fairly share the benefit to each member. This is the major obstructor to promote this idea of collaborative farming. Site-specific yield monitor is necessary in order to be able to record the weight of sugarcane during loading from the harvesters. This monitoring tool would help to make the collaboration farm possible. The yield of sugarcane would be classified to each owner fairly.

This research is intended to study the concept and possibility to develop a hydraulic yield monitoring system. This study focused on developing a laboratory-scale of a hydraulic crane to lift items. Hydraulic pressure was monitored and translated into the weight applied to the system.

2. Materials and methods

A concept of this research is to measure the pressure in the hydraulic system and then convert into force, which relates to the weight of the applied load. A hydraulic system of the lifting crane (figure 1a) is used to simulate hydraulic systems of the side-tipping loading trucks (figure 1b) typically used to collect cane billets from the harvester. The hydraulic system of the side-tipping loading truck is used only to transport the cane billets into a large collecting container outside the field. There are two steps to load the billets into the container. First, the vertical hydraulic cylinders are used to lift the billet basket up above the cane container. Second, the horizontal cylinders extend to dump the cane billets into the container. The hydraulic pressure for lifting the cane basket is related to the applied load and possible to be used as the loadcell to measure the cane billets weight in the basket.

![Figure 1](https://www.combinepart.com)

**Figure 1.** Hydraulic system; (a) lifting hydraulic crane and (b) side-tipping loading trucks (online: https://www.combinepart.com).

2.1. Instruments

The system consisted of following equipment and devices:

1) The hydraulic structure: A hydraulic crane with a single hydraulic cylinder was used in this experiment. The angle of the top arm link is in the range of ±16 to 65 degree. The diameter of the piston bore is 53.03 mm.

2) The pressure sensor: According to Pascal’s law, pressure in an enclosed fluid system is uniform in all direction. Therefore, the pressure can be measured at any location in the system. In this study, a pressure sensor (YF-P1101, Shanghai Yufavor Sensor Instrument, China) was installed to the hydraulic
line near the cylinder inlet on the crane. The pressure sensor provides the output 0.5 - 4.5 V signal corresponding to a range of 0 – 16 MPa.

3) Accelerometer sensor: In order to analyze the force balance, the accelerometer sensors have to be implemented in the system for angular measurement. Two accelerometer sensors (GY-521) were attached on the top arm link and on the surface of the hydraulic cylinder’s tube to measure the corresponding angles of the top arm link and the hydraulic cylinder, respectively.

4) Microcontroller: The M5Stack’s ESP32 Basic Core IoT Development Kit (M5Stack, China) was selected to use as the central controller. It has 12-bit Analog to Digital Converter (ADC) to convert analog signal form the pressure sensor into digital form for further calculation and analysis. It also features a TFT LCD screen for the ease of application development.

The pinout to connect signal cables for M5stack develop kit, pressure sensor, and accelerometer sensors shows in table 1.

Table 1. The pinout for M5stack develop kit, pressure sensor, and accelerometer sensors

| M5stack | YF-P1101 | 1st GY 521 | 2nd GY 521 |
|---------|----------|------------|------------|
| 5V      | VCC      | VCC        | VCC        |
| GND     | GND      | GND,AD0    | GND        |
| PIN 35  | Output signal |        |            |
| PIN 22  | SCL      | SCL        |            |
| PIN 21  | SDA      | SDA        |            |
| 3.3V    | -        | AD0        |            |

2.2. Sensor response
Since the system was designed using low-cost sensors, sensitivity and repeatability of the sensor must be concerned. The sensor was installed to the pressure tank of a pressure pump (Puma, 10-bar, Japan) with a 14-bar pressure gage. The 5V DC power was supplied to the sensors. The pressure generated and stored in the pressure tank was applied to the sensor at 2 to 10 bar with 1 bar interval. The corresponding outputs of the sensor were collected. A calibration model was then developed for the sensor reading.

2.3. Force equilibrium
Force balance model was conducted to determine the effects of the applied load and weight of each component of the crane. The force diagram of the hydraulic crane with the applied load is shown in Figure 2. Considering the moment about the pivot point A, there are two major forces applied to the point B and C in the free body diagram. A resistance from the hydraulic cylinder (\( P_a / A \)) acts at the point B. Point C holds the load (\( W \)) applied to the system. Additional weights from other components, i.e., top arm, hanging chain, and piston rod cause another moment term. Inclinations of the top arm and the cylinder were in small ranges (-10° to 20° for the top arm, and 81° to 83° for the cylinder) affecting a small moment variation. Therefore, this moment term can be assumed a constant and be included in the total moment (\( M \)) term. Tilt angles of the top arm and hydraulic cylinder were measured using accelerometer sensors. The tilt angles were denoted as \( \theta_1 \) and \( \theta_2 \), respectively. The force balance equation is expressed in the equation (1).

\[
M - \frac{P_a}{A} \sin \theta_2 (r_1 \cos \theta_1) + W r_2 \cos \theta_1 = 0
\]

Rearrange to determine the applied load from other parameters.

\[
W = P_a \frac{r_1 \sin \theta_2}{Ar_2} - \frac{M}{r_2 \cos \theta_1}
\]
After installation of the sensors to the system, an experiment was conducted to determine the load prediction model. The applied load and the inclination angle of the top arm were varied to cover experiment conditions. Ten levels of load ($W$), from 5 to 50 kg with 5 kg interval, were applied to the experimental crane using different combination of the test weights in Figure 3(b). There were 7 levels of the top arm inclination angle ($\theta_1$) to be tested from $-10^\circ$ to $20^\circ$ with $5^\circ$ interval. The hydraulic pressure ($P_a$) and the cylinder inclination angle ($\theta_2$) for each factor combination was recorded accordingly. In addition, to be consistent with the equation (1), the angular parameters should be presented and used in the model in the term of trigonometric functions, i.e., $\cos(\theta_1)$ and $\sin(\theta_2)$. The experiment was carried out for three replications. The multiple linear regression analysis was used to develop the model to predict the applied load. The configuration of the developed system is shown in figure 3(a).

3. Results and discussions

3.1. Response of the pressure sensor

Figure 4 presents a linear relationship between the applied pressure and the output voltage. This relationship does not match the specification of the pressure sensor expressed in the document. The relationship obtained from the experiment was be used as the calibration model of the pressure sensor in the further experiment.
3.2. Test of the developed weighing system

Parameters used and measured in the experiment are presented in the table 2. The multiple regression analysis was used to develop the models to predict the applied load. There were two models to be explorer. The first model considered full rank of the parameters including hydraulic pressure \((P_a)\) and the angular factors, i.e., \(\cos(\theta_1)\) and \(\sin(\theta_2)\). The second model looked into the practical aspect. Since the effects from the angular parameters were small and might be neglected. It is more convenient to use only hydraulic pressure to predict the applied load.

| Weight (kg) | \(P_a\) (bar) | \(\theta_1\) (degree) | \(\theta_2\) (degree) | \(\cos(\theta_1)\) | \(\sin(\theta_2)\) |
|-------------|---------------|-----------------------|-----------------------|-------------------|-------------------|
| N | 132 | 132 | 132 | 132 | 132 | 132 |
| Max | 50.00 | 14.84 | 20.18 | 82.73 | 1.00 | 0.99 |
| Min | 0.00 | 4.74 | -10.23 | 81.33 | 0.94 | 0.99 |
| Mean | 24.96 | 9.44 | 4.90 | 82.11 | 0.98 | 0.99 |
| SD | 15.85 | 2.92 | 11.18 | 0.39 | 0.02 | 0.00 |

Table 3 shows the results from both regression model analyses. The first model accounts for the full rank parameters. The coefficient of determination (R² value) was 0.980. However, the regression coefficient for the term \(\cos(\theta_1)\) was insignificant and should be removed from the model.

For the second model which is the linear relationship between the applied load and the hydraulic pressure. The coefficient of determination (R² value) was still as high as 0.978 with high significance of the regression coefficient. The result confirms that, in this system configuration, only hydraulic pressure can estimate the applied load with confidence. The suggested model is:

\[
W = 5.376P_a - 25.769 \tag{3}
\]

This model is similar to the equation (2) when considers \(\cos q_1\) and \(\sin q_2\) being constants due to their small variation. The total moment in equation (2) is also determined and included in the constant term.
Table 3. Regression analysis results

| Model | Unstandardized Coefficients | Standardized Coefficients | t   | Sig. | Adjusted R Square | Std. Error of the prediction |
|-------|-----------------------------|---------------------------|-----|------|-------------------|----------------------------|
|       | B  | Std. Error | Beta |     |       |                  |
| 1     | (Constant) | 576.294 | 210.648 | 2.736 | .007 | .979 | 2.286 |
|       | $P_a$ | 5.373 | .068 | .989 | 78.453 | .000 |
|       | $\sin \theta_2$ | -607.806 | 212.656 | -0.036 | -2.858 | .005 |
| 2     | (Constant) | -25.769 | .695 | -37.099 | .000 | .978 | 2.348 |
|       | $P_a$ | 5.376 | .070 | .989 | 76.418 | .000 |

4. Conclusions

The laboratory-scale of the hydraulic weighing system was developed based on a hydraulic crane. The concept is to measure the applied weight from the pressure in the hydraulic cylinder using a pressure sensor. Two acceleration sensors were used to measure the inclination angles of the structure components that may be used as the parameters in prediction model.

The result demonstrates that only hydraulic pressure can be used to predict the applied weight with the coefficient of determination ($R^2$ value) of 0.978. This outcome shows the feasibility to apply the concept into larger systems such as the yield monitoring system for the side-tipping loading trucks. However, further study with a larger scale should be conducted.

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