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DEVELOPMENT OF AN EXTERIOR-MOUNT REAL TIME SUGAR BEET YIELD MONITORING SYSTEM FOR A SUGAR BEET HARVESTER

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ABSTRACT. The main priorities in crop production are increasing the yield and decreasing the cost of production. Precision farming is the best practice to approach these goals. For real time measurement of sugar beet yield, a yield monitor was developed, and installed on the exterior side of the harvester's chassis. The advantage of this arrangement over similar systems is the location of the load cell and system's frame which prevents blockage by trash, mud or plant roots. For measurement of weight, one load cell on each side of the harvester chassis was used. Conveyor and ground speeds were measured using two proximity sensors. Because vibrations of the harvester can affect the output signals, it is necessary to find the main bandwidth associated with the weights moving on the conveyor. For this purpose, three different masses were placed on the moving conveyor and this bandwidth was determined using signal processing. Then, a suitable filter was designed and undesirable frequencies acting as noise were attenuated. After calibrating all the sensors, final evaluation of the system was performed in the field and the mean and standard deviation of error were 6.48% and 1.52, respectively. Although the error may seem to be somewhat high but the low of standard deviation indicates that there is a similar error in all tests. These negative errors indicate that the weight is systematically overestimated by the monitor. Thus, the error can be reduced by minor changes in conveyor shape or modified by software means. By software modification, the systematic error was alleviated. The median sugar beet yield was thus obtained to be 42.7 t/ha. Comparing this with the actual mean yield of 41.8 t/ha, it differs by only about 2%.

Key words: Sugar beet; Precision farming; Yield monitor; Yield map.

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INTRODUCTION

Increasing the yield and decreasing the cost of production are two main goals in precision farming and preparing the yield map is the first step for reaching these goals. Non-grain crops are generally measured using direct and indirect methods. In the indirect methods, the yield is estimated based on measuring other parameters such as the momentum acting on an impact plate, loss of pressure in the hydraulic actuator, capacitance changes and amount of light received by a detector. However, in the direct method, the yield is directly measured using sensors like load cells. Several studies have been done on products such as potato, tomato and carrot (Compbell *et al.,* 1994; Hofman *et al.,* 1996; Hall, 1998; Pelletier and Upadhyaya, 1999). Godwin *et al.* (1999) developed asystem that could measure the mass cumulative rate of non-grain crops. Several load cells were installed under the trailer, which could measure the added load in the trailer. Test results showed that the difference between the mean values of batch-weighed samples and yield map values was not statistically significant. Two weight sensing systems were developed on a laboratory test conveyor (Walter and Backer, 2003): the first system used 152 mm idler wheels attached to the load cell and the second one replaced two existing idlers on each side of the harvester with slide bars covered with UHMW plastic. Results demonstrated that the error in laboratory tests was between 2 and 3%. Mass flow rate has been measured by counting the number of moving roots on the conveyor (Schmittmann and Kromer, 2002). The weight of mediocre root was considered as a constant coefficient and its multiplication by the counted number of roots led to a measure of the mass flow rate. For determining potato mass flow rate, two types of transducers were investigated (Mostofi *et al.,* 2007). In the first one, a cantilever beam was mounted on both sides of the conveyor and, in the second one, four load cells were installed under the container. In this study, the effect of the number of active idlers on the system accuracy was investigated. Results indicated that use of two idlers would give the lowest error. Pelletier and Upadhyaya (1999) developed a yield monitoring system for mounting on the tomato harvester. The coefficient of determination between the actual and predicted weights was 0.977. Hennens *et al.* (2003) used a curved side rack as a mass flow sensor for measuring the force exerted on the rack of the cleaning unit. In this study, by calculating the amount of momentum, the flow rate was obtained. When only momentum was used, the prediction error was about 20%; but, using the immediate rotational speed, caused the error reduction to 5%.

The principle of using the image processing for separating clods and stones from roots was also evaluated by some authors (Gogineni *et al.,* 2002), but this system could not properly discriminate roots from clods and mud. Yield measurement based on ultra-wideband (UWB) radar technology was applied by Konstantinovic *et al.* (2008). The main objectives of his study were to detect sugar beet in the soil and estimate its size. The results indicated that this method could detect 90% of root in the soil and the best correlation between mass of sugar beet and the amount of backscattered energy exceeded 80%. Acapacitive throughput sensor for potato and sugarbeet was tested by Kumhála *et al.* (2009). In this study, two metal sheets (830*260*2 mm) were used as capacitive plates. These plates were mounted parallel up and under the conveyor. Although this method was not affected by the vibration, changing the filling regimes of the passing materials led to dramatic change in the throughput sensor; in conclusion, this methodis suitable for products that have no changes in their filling regimes.

The main goal of ours study was to develop a yield monitoring system for sugar beet using a weighing platform on the exterior side of the harvester. The advantage of this arrangement over similar systems is the location of the load cell and system's frame, which prevents blockage by trash, mud, or plant roots. This platform is suitable for harvesting machines that do not have enough space under the conveyor for mounting necessary instruments.

MATERIALS AND METHODS

In this study, a pulled-type sugar beet harvester (BATITCO, Garford, England) was used as the machine to be equipped with the yield monitor (*Fig. 1*). This machine has two conveyors. Since there were not suitable places in the upper conveyor, the lower conveyor was chosen for mounting the platform on the harvester.

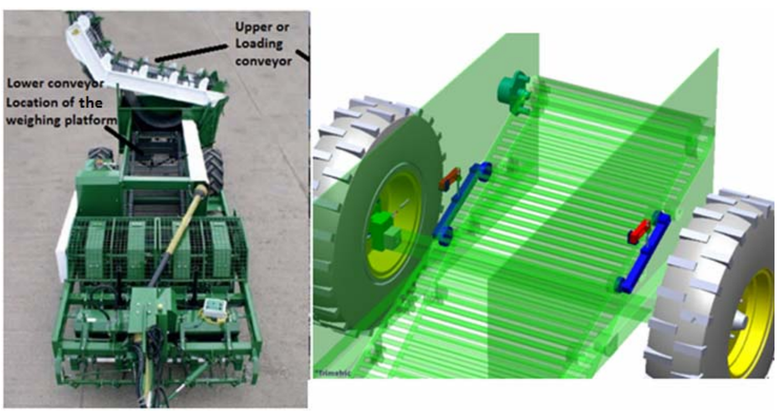

Figure 1 - a) A general view of the sugar beet harvesting machine; b) Weighing platform and its location on the machine

As shown in *Fig. 2b*, the two old rollers (in positions 1 and 3) were replaced by new ones. Roller 3 was completely suspended; roller 1 was supported by a bearing and could rotate with one degree of freedom. In addition, the load cell was horizontally mounted (*Fig. 2b*) to measure the perpendicular forces exerted on the assembly. The conveyor and ground speeds were measured using proximity sensors (RDL30-25DP, Korea, Autonics). For inducing pulses, two target blades were attached to the conveyor - driven shaft and six blades were welded on the rim of the harvester's wheel.

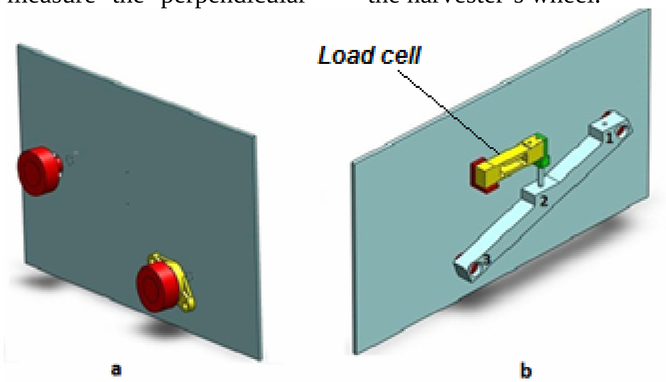

Figure 2 - Scheme of weighing platform: a) inner side; b) outer side

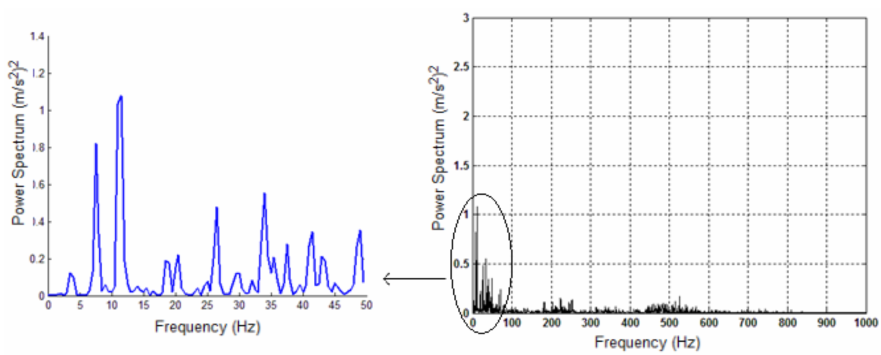

Figure 3 - Frequency spectrum of the sugar beet harvester where the platform was mounted.

Because the vibration of the frame where the load cells are mounted is in fact perceived as noise, it was necessary to determine the bandwidth of the vibration near the load cell base. In this study, the frequency component of vibration was obtained using an accelerometer (CTC, USAAC192). As shown in *Fig. 3*, some components of the vibration were present at low frequencies. Because these vibrations could affect the load cell throughput, it was necessary to use a special method for determining the frequencies at which the moving load was detected. In this method, three different weights (5, 10, and 20 kg) were passed through the platform in operation. After analyzing the spectrum, three peaks (one for each test weight) were expected to appear at a particular frequency. All signals were acquired using data acquisition card (High Speed card, HLC Group, Iran) and then recorded and analyzed using LabVIEW program. In this program, load cell output was sampled at 4000 S/s and, after attenuation by the filter, the average was recorded as weight data in the data sheet. In this program, it was possible to display online all important parameters such as mass flow rate, field yield, conveyor, and ground speed on the monitor.

Load cell output, conveyor speed, and ground speed are the main parameters necessary for determining the mass flow rate. The load cells were mounted horizontally and the conveyor had a fix angle, thus, it was not necessary to use an angle sensor. Mass flow rate (kg/s) and field yield (ton/ha) were obtained using Equations 1 and 2, respectively.

$$FR = \frac{F \times V}{D} \quad (1)$$

$$Y = \frac{36 \times FR}{GS \times W} \quad (2),$$

where FR=sugar beet flow rate (kg/s), F=load cell output (kg), V=conveyor speed (m/s), D=platform width (m), Y=sugar beet yield (ton/ha), GS=harvester ground speed (km/h) and W=harvester width (m).

Prior to evaluating the system in the field, all sensors were calibrated in the laboratory. For final evaluation, five trucks of sugar beet were harvested and for each truck the error in weight determination was calculated using the net weight of the collected sugar beet and the weight estimated by the system.

Dynamic analysis of the platform

To ensure that resonance did not occur in the platform, modal analysis was performed using Ansys V.10. For doing this analysis, the platform was modeled as shown in *Fig. 4*. BEAM3 and COMBIN14 were used as elements to model the beam and the spring, respectively. BEAM3 is a uniaxial element with tension, compression, and bending capabilities and COMBIN14 has longitudinal or torsional capability in one, two, or three dimensional applications.

Based on the results of the accelerometer sensors, the bandwidth of the vibration was about 500 Hz. In comparison with the results of modal analysis, in which the first natural frequency was 708 Hz, it was concluded that the platform would not resonate.

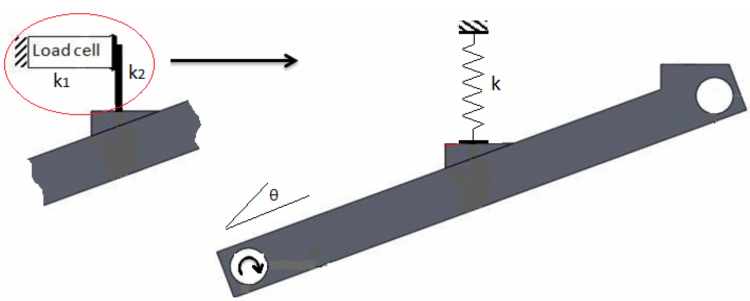

Figure 4 - Schematic model of weighing platform for dynamic analysis

RESULTS AND DISCUSSION

Attenuating the noise as a result of mechanical vibration is the main problem in signal processing. In this study, a practical test method was used for finding the frequency at which the moving weight was detected. For finding the desired frequency, three different weights were moved on the conveyor. After frequency analysis, proportional to the weights, three peaks were found at 0.3 Hz (*Fig. 5*). Also, according to *Fig. 3*, there was no vibration between 0 and 1 Hz. Thus, using the low-pass filter with a cutoff frequency of 0.8 Hz, the noise was attenuated.

Raw and attenuated signals are shown in *Fig. 6*. A clear shift in the signal can be seen at about 2.5 seconds which corresponds to the delay time, the time required for the beets to reach the weighing section. Thus, the time delay was considered to be 2.5 s in the system software.

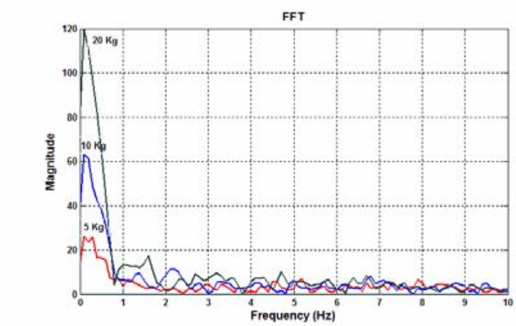

Figure 5 - FFT of signals resulting from three different weights loaded on the moving conveyor

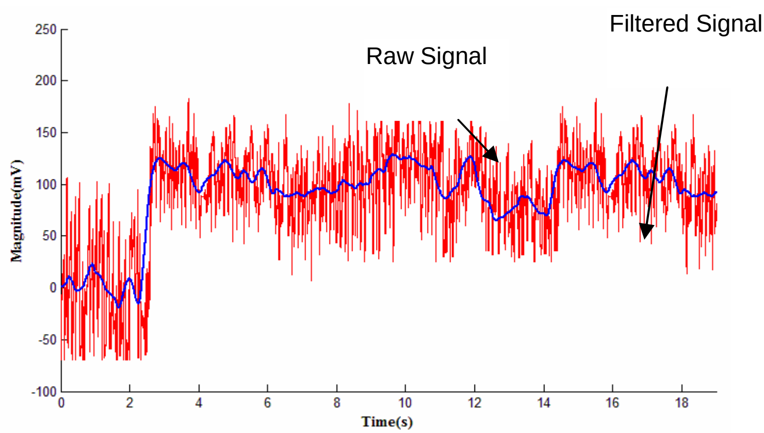

Figure 6 - Sample of load cell output during the harvest of sugar beets

After calibration of the system in the laboratory, the final evaluation was conducted in the field. The data collected while harvesting five trucks are shown in *Table 1*. As seen in this table, for all tests, the weight was overestimated by the system. Observation of harvester conveyor revealed that some roots would roll down while moving up the conveyor. The weight of these roots would be recorded more than once by the system resulting in slight overestimation. Since the standard deviation of the error is low, hardware or software remediation is possible. In other words, if the shape of conveyor or the system program were correctly modified, yield monitoring error would be reduced. Here the simpler software option was implemented: for reducing the error, the mean value of the errors, 6.48%, was used as a correction factor in the software. Then, the field test was repeated and led to better results. After modifying the software, the product was harvested again and three trucks of sugar beet were weighted (*Table 2*). According to these results, it is concluded that this system can estimate the yield of sugar beet with low error and it can be used as a suitable monitoring system on sugar beet harvester.

Table 1 - Comparison of actual and measured weights

Truck no.	Gross weight (kg)	Calculated weight (kg)	Error (%)
1	6800	7254	-6.67
2	6320	6640	-5.06
3	5402	5750	-6.48
4	6405	6745	-5.30
5	5950	6480	-8.90
Average			-6.48
Standard deviation			-1.52

Table 2 - Comparison of actual and measured weights after modifying the system

Truck no.	Gross weight (kg)	Calculated weight (kg)	Error (%)
1	5309	5442	-2.51
2	6310	6441	-2.08
3	4980	5053	-1.48
Average			-2.02
Standard deviation			-0.51

For final evaluation, 2.8 ha of the test field was harvested and two weights, measured by conventional weighing and by the monitoring system were compared. The means of two values were obtained to be 41.8 and 42.7 ton/ha, respectively, which demonstrates an accuracy of 2.1%.

CONCLUSIONS

All parts of the developed weighing system are located on the exterior of the chassis, comparing with similar systems, decreasing the possibility of blockage by mud, trash, and roots are the main advantages of this system. The vibration problem encountered on such yield monitors was attended to lay experimental determination of the desire bandwidth based on which a low-pass filter was designed and implemented to attenuate vibration noise. Although the mean error of yield in the initial test was high (6.48%), after modifying the system program, it was decreased to 2.1% rendering the system suitable for yield monitoring.

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