DESIGN AND CONSTRUCTION OF AN ULTRASONIC CUTTING WIDTH SENSOR FOR FULL-FEED TYPE MID-SIZED MULTI-PURPOSE COMBINES

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ABSTRCT

Precision agriculture analyzes the spatial variability according to the characteristics of an optimum setting of agricultural materials. To raise the profitability of agriculture and to reduce the environmental impact, technological research and development of precision agriculture has been conducted. In Asian countries such as Japan and Korea, yield monitoring system and crop growth sensors for rice and dry-land crops have been studied. Market for full feed type combine harvesters is recently growing in many countries including Republic of Korea. Yield monitoring system is one of the recent trends of the combines, and the major components consist of a positioning system, grain flow and water content sensors, ground speed and cutting width sensors. Objective of the paper was to design and construct an ultrasonic cutting width sensor for full-feed type mid-sized multi-purpose combines, as a part of a yield monitoring system, targeting row-planted and broadcasted rice, barley, wheat, soybean, and rapeseed. The target combine harvester was 55-kW full feed types for various crops with about 20% of the grain water content. Cutting width was about 200 cm, a maximum working speed of 1.7 m/s, and the turning radius of 1.5 m, and overall loss of 1.5% or less. First, an experimental device with paired ultrasonic sensors was designed and constructed. Two ultrasonic sensors (UDS-10A) were mounted on a frame, shaped of a combine header, connected to a computer through an USB port, and the data were obtained with customized software. Then, calibration tests were conducted in various conditions. Basic performance of the ultrasonic unit was validated by confirming distances to the wall. The tests were conducted from 50 to 200 cm with a 10-cm interval, and the results proved the accuracy, showing that the coefficient of determination of the linear regression was 0.99. Average and maximum errors of the tests were 1.7021 cm and 0.9686 cm, respectively. The experimental unit was also tested for field conditions. Distances from the crop were varied from 0 to the full cutting width (i.e., 210 cm), and the signal was collected for 1 minutes at stationary condition with 3 replications. Average and maximum errors were 2.5195 cm and 4.8021 cm, respectively. Next, in order to know the possibility of the measurement of actual combine width with the above experiment method, the distance with the crop has been moved (around 1.7m/s) for the measurement. Average and maximum errors were 2.2934 cm and 5.4763 cm, respectively. However, the value was not adequate for the measurement of cutting width, which was minimum 82.3% which must have used all the data. Results of the study showed a good potential of the fabricated cutting width sensor. Future study would include dynamic tests, combine installation and field tests during harvesting season, and optimization with other components of the yield monitoring system. Also, future study will develop a data process algorithm for the precise real time measurement of cutting width.

Keywords: Combine harvester, Yield monitoring system, Cutting width, Ultrasonic sensor

INTRODUCTION

Development of combines that could maintain high field efficiency for various crops such as rice, barley, and soybean, which is major food crops in Japan and Korea (Kim et al., 2003), has been an issue in Asian countries. When compared to the US average farmland per household of about 190 ha, Korean average farmland per household is about 1.3 ha (FAO, 2006), therefore mid-sized (e.g., cutting with less than 3 m) multi-purpose combines are preferable for greater utilization time. Also, according to the Food and Agriculture Organization of the United Nations it was reported that use of agricultural pesticide per ha per year in Korea was 20 times of that of Norway. With adoption of high technologies such as precision agriculture, production increase, water consumption reduction by 30%, and energy saving by 60% would be expected (FAO, 2012). Recently, yield monitoring and mapping systems have been important options of combine harvesters in many countries, including Korea.

Grain yield monitoring and mapping system is one of the technologies of precision agriculture that have been studied, developed, and commercialized. A yield monitoring system collects flow rate and water content of grain, cutting width, travel speed, and location of the combine while harvesting. Yield map is a graphical representation of geo-referenced grain yield so that variability of the yield can be identified. Producers may change the production inputs and pursue direct profits based on the information from the yield maps (Arslan, 2008; Birrell et al., 1996). Accuracy of yield map is influenced by various factors such as location error, sudden change in harvesting condition, changing harvesting width, and sensor error (Chung et al., 1999).

Grain yield is generally expressed as mass or volume per harvested area. Mass or volume is obtained by measurement of flow rate and water content, and harvested area is calculated by harvesting width and distance (time x speed). Harvesting or cutting width needs to be measured accurately if it is not constant. Mechanical, image, and ultrasonic sensors have been used for real-time measurement of the cutting width. Wild and Auernhammer (1998) compared different methods (mechanical, ultrasonic, and image processing) to measure the cutting width and found that the ultrasonic sensor method showed the best accuracy. Stafford et al. (1997) compared accuracy of the ultrasonic sensor and the ultrasonic vibrator. They measured the distance to the paddy rice from the devices and found that the maximum error of the ultrasonic sensor was 4.2% when the true distance was 720 mm, and that of the ultrasonic vibrator was 8.9% when the true distance was 360 mm. Missotten (1998) and Reyns et al. (2002) used an 90-degree rotated ultrasonic sensor and reflecting plates to measure the distance from the crops for measuring the blind spots. The errors were less than 5%, but the new design required additional parts and spaces compared to the previous designs.

Objective of the paper was to explore the potential of an ultrasonic sensor for cutting width measurement of a full-feed type mid-sized (55 kW level) multi-purpose combine through stationery and moving tests.

MATERIALS AND METHODS

Design and construction of the cutting width sensor

Figure 1 shows a schematic diagram explaining principle of the cutting width measurement at the front part of the combine header using ultrasonic sensors. Designed maximum travel speed, harvesting width, cutting height of the combine were 1.7 m/s, 2 m, and 0.1~0.3 m, respectively. Main target crops were rice, barley, soybean, wheat, and rapeseed, which row planted or broadcasted. Ultrasonic distance sensors are mounted at the front part and on both sides of the combine header. The ultrasonic distance sensor shoots out ultrasonic waves and measures the wave-returning time to calculate the distance from the object (Son, 2012).

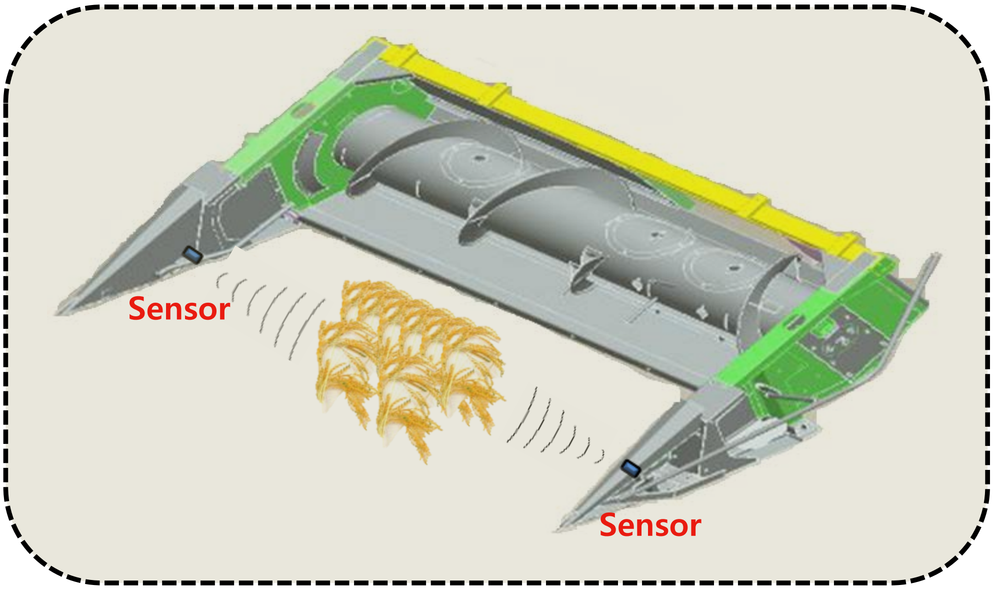


Figure 1. Schematic diagram explaining cutting width measurement at the front part of the combine header.

The ultrasonic distance senor selected in the study (Model: UDS- 10A; DAS co., Hwaseong, Korea) measured distances of various fields and it was small (24 x 27 x 51 mm) and light (25 g). The sampling speed was 40 Hz and the sensing range was 300~60,000 mm. With the maximum design speed of 1.7 m/s, the sampling distance interval would be 42.5 mm. The average bottom radius of the Korean rice paddy stalk was 100 mm and the wave emitting angle of the sensor was 15 degrees, so the selected sensor would detect the rice stalks.

To interface the distance sensor, a data acquisition device (DAQ) (Model: NI-USB6009; National Instrument co., Austin, Texas, USA) was selected. The DAQ had 8 analog (14 byte, 48 kS/s) inputs, 2 analog (12 byte, 150 S/s) outputs, 12 digital I/O ports, and 32-byte counters. It was easily compatible with bus power supply, internal signal linking, and software languages such as LabVIEW and Visual Basic.

Performance evaluation tests

In order to judge, if the actual combined cutting width can be possible using an ultrasonic sensor, three methods of experiments were used.

First, performance assessment test of the ultrasonic sensor was performed using the distance with the wall.. Since the combined cutting width is under 200cm, the distance with the wall was placed at an interval of 10cm from 50cm to 200cm, 3 times for 1 minute each. The actual distance with the wall and the output value of the ultrasonic sensor were compared and the correction formula was calculated. The precision of the ultrasonic sensor was measured using the calculation experiment and the measurement of the distance with the crop was also verified.

Next, by inserting the correction formula calculated using the distance with the wall into the data collection program, the distance with the crop during stoppage was measured. The test was conducted in November, 2013 in Chungnam National University (CNU), College of agriculture and life science's affiliated farmhouse where harvesting was not completed yet but the rice was grown well. Using the correction equation calculation that used the distance of the rice, we verified whether the distance of the rice was possible by measuring the accuracy of the ultrasonic senor. Installing a tapeline at the end of rice a test was conducted by putting a distance up to 50 ~ 200 cm in 10 cm between and repeating 3times per minute between the combine because its cutting width is below 200 cm. Using the date of the test which was repeated 3 times, the error was compared of the measures tapeline and the real distance.

Finally, the experiment to judge the possibility of application of actual combined cutting width measurement was performed. This test was conducted to see whether the produced cutting width system that is installed the real combine can adjustable or not. Through the basic performance evaluation test of the ultrasonic senor, accuracy verified program and ultrasonic senor were used. The experiment was also conducted in the same site of CNU. In order to measure the distance of rice while moving, after measuring up to 50 ~ 200 cm in 10 cm between with the tapeline measuring each distance of the stage, the movement direction of the ultrasonic senor was marked with a line. Because the production speed of soon to be developed combine is 1.7m/s like the basic performance evaluation test, a test was conducted with up to 50 ~ 200 cm in distances of 10 cm repeating 3 times. Figure 2 shows Measurement system and schematic diagram (Moving condition).

After the cutting width measurement, a decision where it was possible to apply it to the real combines. The real distance was measured with a ruler, and output value of the sensor was compared to see the errors and to identify if it is possible to apply or not.

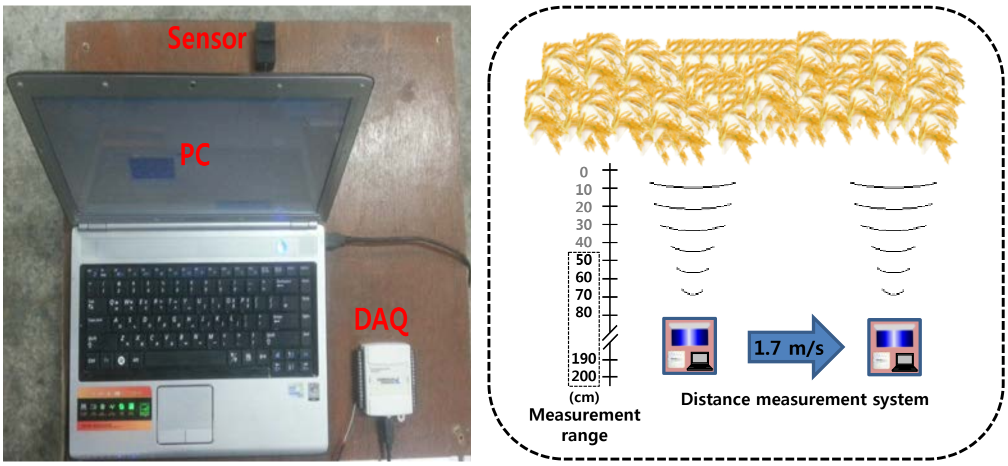


Figure 2. Measurement system and schematic diagram (Moving condition).

RESULTS AND DISCUSSION

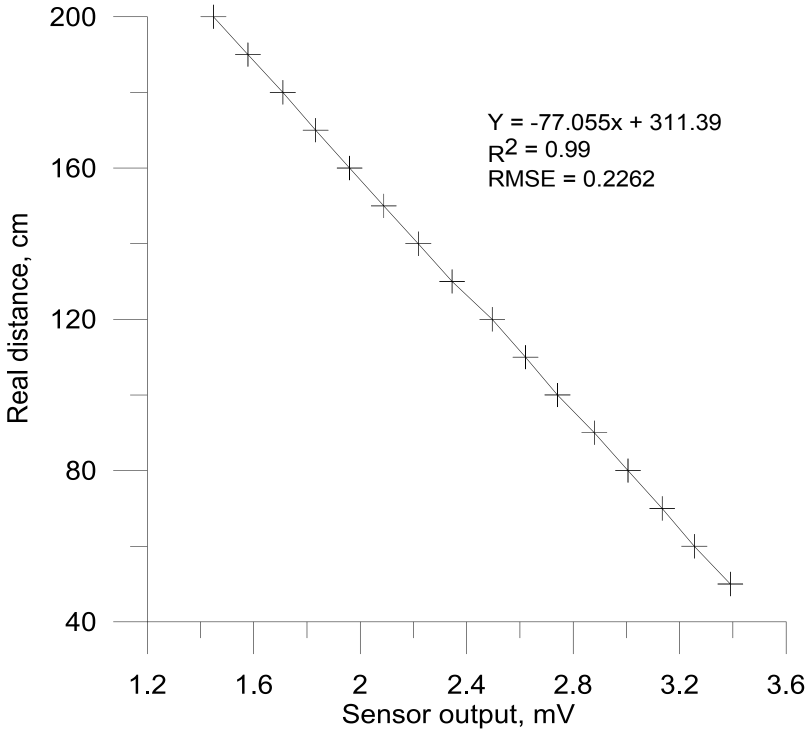
The average of the 16 data which were measured in an interval of 10cm from 50cm to 200cm was used to calculate the correction formula. The calculation of correction data using all the data was also proceeded and the same result was obtained.

The Figure 10 shows each output voltage from the sensor from each distance with the wall using the distance measurement system. The change of the voltage depending on the increase of the distance showed a linear inverse relationship. The correction formula was deducted using verified data as follows.

In the deducted correction formula, the R^2 was 0.99, which showed a high co-relationship.

$$Y = -77.55X + 311.39$$

The error was 1.7021 cm maximum and 0.9686cm on average and the precision was 98.2% minimum and 98.9% on average, which is high value. Judging from the value of the R^2 of the correction formula and the precision of the measurement seen in the Figure 10, it was judged that there will not no problem in applying the ultrasonic sensor used in the computation of the correction formula in the actual crop and performing the cutting width calculation experiments.



Fiugure 3. Calibration graph of sensor output and real distance.

To identify, if it is possible to measure the distance to the crop using the ultrasonic sensor, an experiment was carried out. Here, this study used 16 kinds of data which measured the distance at intervals of 10 cm from 50 cm to 200 cm. Then, the actual distance measured with a tapeline was compared to the output value of sensor.

Figure 5 shows the comparison between the real distance and output distance by inserting the correction equation in the distance measuring system. The change in voltage that is in accord to the increase in distance showed a R^2=0.99 value and linear relationship. Figure 6 shows the output mV value of all the data that is different than the 16 points which is 50 to 200 cm.

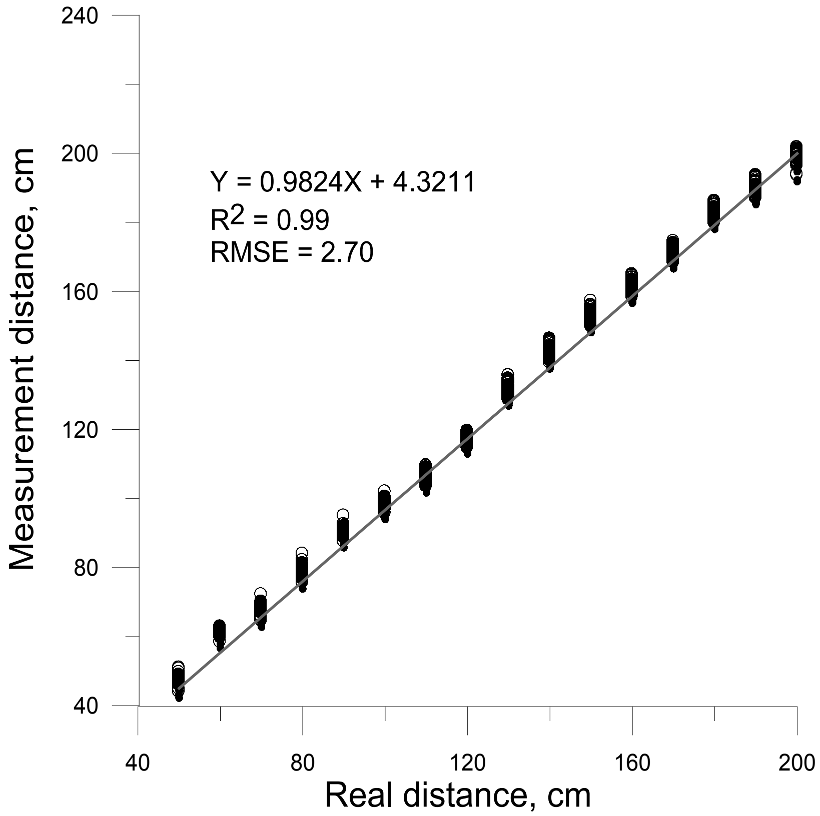


Figure 4. Graph that compares the real distance and output distance.

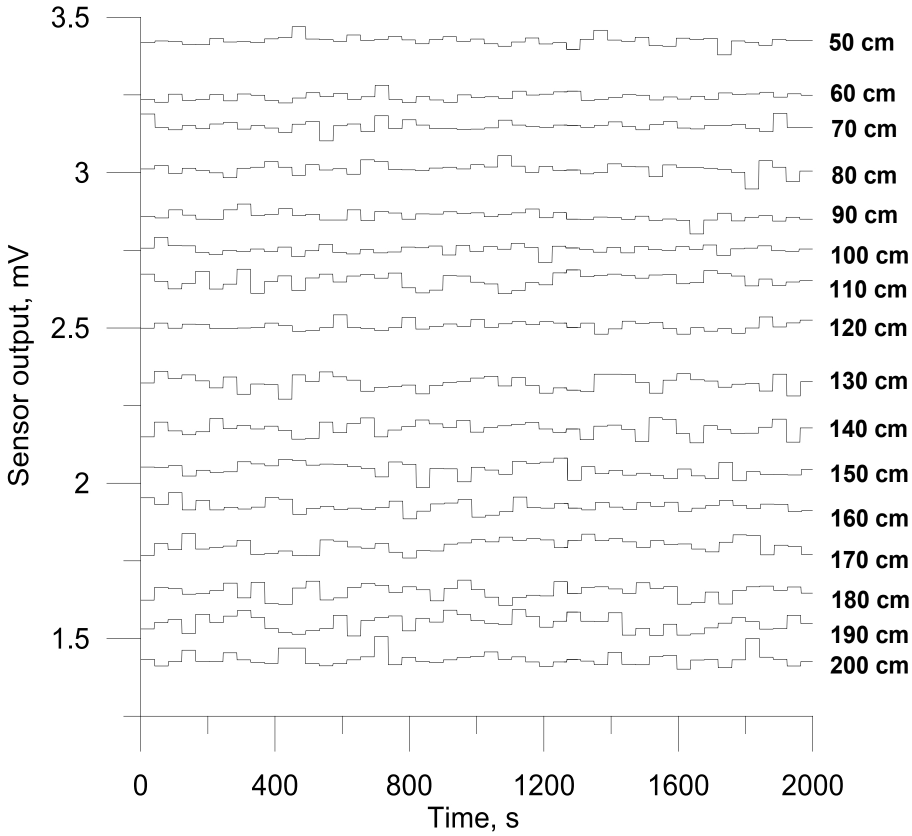


Figure 5. Sensor output from 50 to 200 cm in distance.

The difference was almost 4.8021 cm and on average 2.5195 cm. The accuracy was minimum 97.7% and on average 98.6%, showing a high value. It shows that the average error result value agrees with the ±5% error that was the goal. Also, it is shown in Figure 6 that the sensor value comes out evenly in each branch. Therefore it was decided that when seeing all the data error and sensor output of each branch, there was no problem in using the distance measuring system for the measuring the distance between crops in a paused state up to 50 ~ 200 cm.

A test was conducted to decide if measuring distance was possible using an ultrasonic senor while working with a real combine. The distance of the rice using the invented distance measuring system was measured in moving condition. Using the distance of the rice when it came to a halt, with the measured data as the base, the same distance was measured and compared. Table 1 shows the compared value between the real distance of each sector while moving and average output distance.

Table 1. Compared to the real distance and average output distance(Moving condition).

Real distance(cm)	Measurement distance(cm)	Error(cm)	Accuracy(%)
50	51.0223	-1.0223	98.0
60	62.9111	-2.9111	95.4
70	71.445	-1.445	98.0
80	82.164	-2.164	97.4
90	92.525	-2.526	97.3
100	102.0443	-2.0443	98.0
110	111.1443	-1.1443	99.0
120	122.2243	-2.2243	98.2
130	132.345	-2.345	98.2
140	137.3566	2.6434	98.1
150	146.68	3.32	97.8
160	157.3879	2.6121	98.3
170	172.9834	-2.9834	98.3
180	184.133	-4.133	97.7
190	184.5237	5.4763	97.1
200	189.8777	1.1223	99.5

The difference was almost 5.4763 cm and 2.9234 cm on average. The accuracy was 95.4% minimum and 97.9% on average showing a high value. Also, like in Figure 7 it shows the value of R^2 and value of RMSE.

From the average date difference and accuracy of the 16 branches one can decide that real combine cutting width measurement is possible. However, when actually working instead of the real-time output value was used instead of the cutting width measurement average value, so all data was used and analyzed. Figure 8 is drawn using all the data

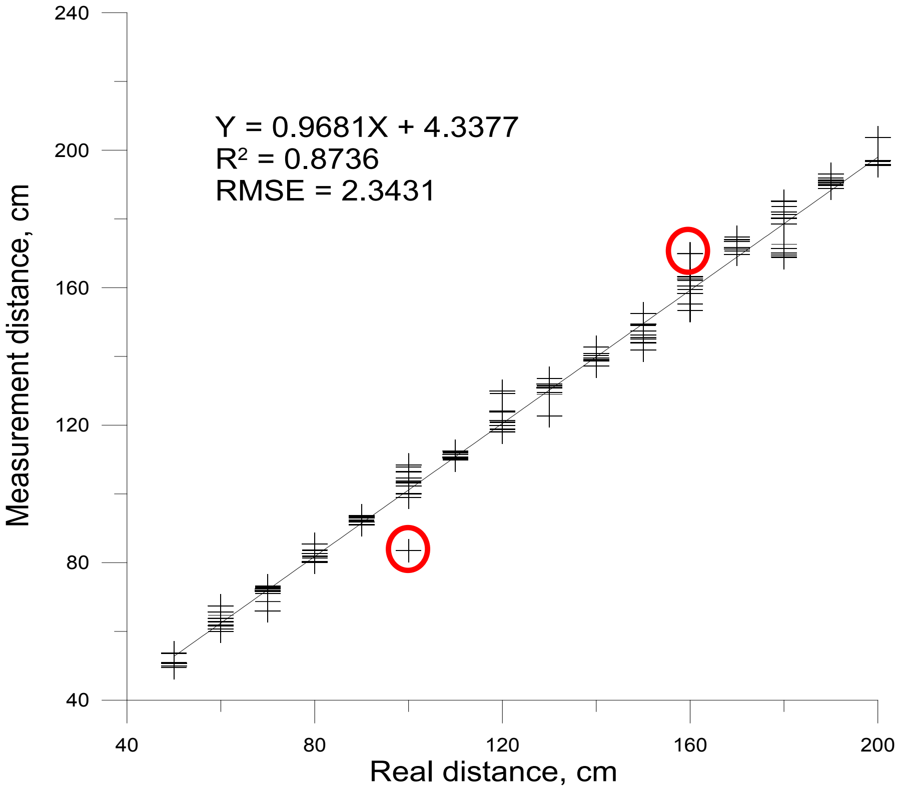


Figure 6. Compared to the real distance and output distance (All of the data).

When a graph is drawn using all the date like in Figure 7, a sudden difference can arise. The difference was almost 9.6432 cm and the accuracy was 89.2% minimum. When the data was analyzed there was a sudden difference. The difference that came from that analysis was decided that it came from the shaking of the bend senor on the surface or the appearance of the output and not that value of the real distance being due to the sudden error in the sensor.

Using the average data like in Table 1, it can be used in drawing a harvest map after the working with the combine. However, the result of the distance measured while moving does not agree with the aimed difference. Therefore, it was decided that measuring the cutting width in real time was impossible and was unable to have accurate measurements due to sudden differences.

According to the previous research result, error data should be corrected through data processing to measure the actual combine cutting width. As marked in Figure 7, an abnormal error should be detected and corrected. First, a value above or below a certain level is judged to be an error by comparing the mean output value, when there is a real-time sensor signal. Once error data is corrected using the mean value of adjacent values, and a modified graph is printed out in the monitoring part. Therefore, in further research, a program to perform this task will be produced and a cutting width measuring system will be installed in the actual combine.

CONCLUSIONS

In this study, we build a distance measuring system to measure the cutting width of the conventional combine by using an ultrasonic senor and its performance was also evaluated. First, a literature investigation, market research, and indoor test were conducted in building and choosing the distance measuring system. A program was developed using the LabVIEW for the building of the distance measuring system. The ultrasonic senor and NI-USB6009 was used. Lastly, using the distance measuring system that was built with the distance of the rice, a correction equation calculation was made. A measurement of distance and difference was made in the field where the real rice was grown and performance evaluation was made.

1) According to the correction formula calculation result using the distance with the wall in order to investigate the applicability of the distance measurement system using ultrasonic sensor, a credible result of R^2=0.99 came out, the error was 1.7021cm maximum and 0.9656cm on average, and the precision was 98.2% minimum and 98.9% maximum, a high value. From these results, it is judged that the distance measurement can be possible using ultrasonic sensor in the actual crop.

2) In order to check if the distance measuring system was possible with the ultrasonic senor, a trustworthy result of R^2=0.99 value was shown which used distance of the rice when paused. In comparing the real distance and the output distance the difference was almost 4.8021 cm and 2.5195 cm on average. Accuracy was 97.7% minimum and 98.6% on average, showing a high value. From the aimed difference, it shows that the measuring distance using ultrasonic senor on crops is possible.

3) A measurement between the distances of the rice while moving was made to identify, if it was possible measuring the cutting width measurement of the real combine which uses the distance measuring system. All the data measured using the distance of rice 50 ~ 200 cm and 10 cm in between was different 9.6432 cm maximum and 82.3% accurate minimum. It was decided as a sudden ultrasonic senor error. A data processing algorism that can modify the sudden difference of the senor and shaking due to the bent surface of future studies is demanded.

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