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Application of Time-of-Flight (ToF) Laser Sensor for Real-Time Cutting Width Monitoring System on Mini Combine Harvester

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ABSTRACT

Yield monitoring is a precision farming technology that monitors crop yields in real-time. The cutting width is one of the variables gathered by yield monitoring. The cutting width is measured using the sensor by subtracting the width of the header from a distance reading from the sensor to the rice installed on the left and right sides of the mini combine harvester header. This research aims to design a cutting width measurement system using the VL53L1X ToF sensor on a mini combine harvester. The VL53L1X ToF Sensor is used as a distance sensor, followed by an ESP-32 microcontroller and a WiFi module. These are linked to the database and interpreted into digital form using an I 2 C LCD so that the user may see the results afterward. The accuracy of the two sensors (left and right) is evaluated by comparing distance measurement results on an object with an R^2 value of 1. For static testing on rice plants (Oryza sativa L), ten data collecting variations with three repetitions were conducted, with an average R2 of 0.9975 throughout the three repetitions. The dynamic test system includes an Ublox GPS tracker used to read coordinates for variability mapping of cutting width on ArcGIS application using the kriging method. The kriging result shows five different cutting width classes and the difference in variability in harvesting on the field.

1. INTRODUCTION

Precision farming ensures the right action and position at the right time using the right method (Manalu, 2013). Precision farming utilizes a systems approach to obtain excellent and optimum yields by paying attention to input, process, and output. *Precision farming includes yield monitoring, which can provide helpful information for land management*. Nutrients lost during harvesting, estimating expected earnings, creating working zones, and analyzing the effect of specific treatments on the soil are all examples of information collected via yield monitoring (Fulton *et al*., 2018; Yuswar, 2004). A yield map will be created using the data collected during yield monitoring. Yield mapping is the output of graphical interpretation of harvest yield data to identify yield variability that can affect production capacity (Missotten, 1998). Producers might modify production inputs to maximize profitability depending on information acquired via yield mapping (Arslan, 2008; Birrell *et al.*, 1996).

Measuring the harvester's cutting width is one of the most critical aspects of getting an accurate total yield during the harvesting process for rice commodities (*Oryza sativa* L). The distance from the mini combine harvester header is commonly used to calculate the cutting width. Manually measuring the cutting width can be done by multiplying the plant interval by the row. However, this is ineffective when harvesting with an instrument like a combine harvester leaves areas uncut. This condition leads to inaccuracies in harvest yield measurements, resulting in yield variability, which influences the cutting width's value. Yield variability is affected by various factors, including weather, genetics, and field management, according to Putri *et al*. (2016a; 2016b). The appropriate cutting width calculation can also increase yield measurement accuracy. The cutting width can be measured in real-time during harvesting using a sensor to measure the area cut off at the harvester's header (Stafford *et al*., 1997). Putri *et al*. (2021) conducted a study by attaching a yield monitoring system to a combine harvester and taking one of the parameters, namely cutting width. The cutting width was measured using an Omron EP4A-LS200-M1-N ultrasonic sensor, indicating that the sensor can read the cutting width accurately, with $R^2 = 1$. Zheng *et al*. (2013) used the SICK LMS 511 Lite ToF laser sensor to measure plant height with acceptable error levels of 2.1 to 8.5 %.

The data obtained from measuring with sensors can be obtained in real-time and saved in a database. The sensor used in this research is a VL53L1X type Time-of-Flight (ToF) laser sensor. TOF It is the fastest miniature ToF sensor on the market with accurate ranging up to 4 m and fast ranging frequency up to 50 Hz. This sensor calculates the time for the laser to travel from the emitter to the receiver. With the help of a mini combine harvester, this research should be able to measure the cutting width during the harvesting process correctly. Later, the ToF laser sensor will be installed on the right and left sides of the mini combine harvester's header to measure distances from both sides of the header and determine how much is the cutting width. The objective is to design a cutting width measurement system using the VL53L1X ToF sensor on a mini combine harvester

2. MATERIALS AND METHODS

In this study, an experimental methodology was employed. The VL53L1X ToF sensor must first conduct an accuracy test by comparing its distance reading to the actual distance using a meter with ten variations of the object's distance. To determine whether the two sensors can accurately measure the cutting width on rice plants, a static test will be conducted using rice plants after obtaining the regression value from the accuracy test. Three plots of rice fields were created, and the sensor was tested in the field on a tiny combine harvester to see if it could measure the cutting width. To read the track of the tool's movement while harvesting, the tiny combine harvester includes an Ublox GPS type attached to it. The research was carried out in several stages, including:

2.1.Design

The phases of this research design are the prototype design of the automatic cutting width measurement system and the design of the control system for the automatic cutting width measuring instrument based on the VL53L1X ToF Laser Range Finder sensor.

a. Prototype Design

The mini combine harvester used is a Kubota DC 35 mini combine harvester with a four -stroke diesel engine that produces 33.3 HP at 2400 rpm. The dimensions of this machine are 4120 x 1850 x 2150 mm, with a 1600 mm header width and a weight of 1550 kg. Sensors will be installed on each side of the mini combine harvester header.

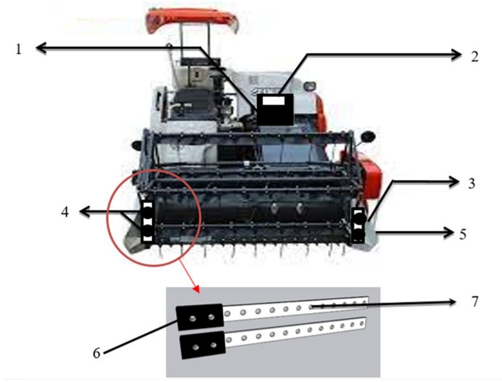

Figure 1. System Overview (1. Microcontroller; 2. LCD; 3. Bracket; 4. Ultrasonic sensors; 5. Headers; 6. VL53L1X sensors; 7. Bracket hole)

b. Mechanism of Cutting Width Measurement

In real-time, the VL53L1X ToF sensor reads the cutting width of the unit header from the mini combine harvester. Afterward, the sensor will be mounted on the left and right headers, with a bracket functioning as a sensor holder. Readings from the VL53L1X ToF sensor will be delivered to the ESP 32 as a microcontroller. They will be processed before being displayed on the LCD in digital form via I2C communication and stored in the database.

2.2.Installation and Testing of Cutting Width Measurement Control System

Carry out installation and testing of control systems consisting of 1) preparation of tool stands, 2) calculating system power requirements, 3) component assembly and installation to stands, 4) sensor accuracy tests in static conditions, and 5) field tests.

a. Preparation of Bracket

This study utilized two brackets constructed of angled iron with holes with a length of 30 cm and 1.4 mm of thickness. The brackets will later be put on the left and right of the mini combine harvester header with the help of 13-inch nuts and bolts, allowing the bracket to be disassembled.

b. Calculating System Power Requirements

The power requirement is adjusted to each component's power requirement and to the power source used, specifically DC sourced from a dry battery with a voltage of 12V so that the system can turn on.

c. Component Assembly and Mounting

Jumper cables connect the ESP 32, the VL53L1X sensor, and the LCD. Then each of these components is connected to the power source, which in this case is the battery.

The VL53L1X sensor is mounted to the mount with nuts and bolts to ensure that it is securely fastened.

d. Accuration Test in Static State
The goal of the accuracy test is to see if the sensor can correctly read the cutting width so that the output is accurate and precise. The data from the sensor readings (predicted value) will be compared with the actual measurement findings (absolute value) using a laboratory ruler for this accuracy test.

e. Field Test
Field tests were carried out to determine the sensor's performance on the reading of the cutting width during the harvesting process. Field trials were carried out on rice fields owned by farmers in the city of Padang. The rice field criteria selected for field testing on the measurement of the *cutting width* are rice fields that are ready to harvest.

2.3.Observation

2.3.1.Cutting Width Under Static Conditions

Observation of cutting width in static conditions is conducted from a fixed location, ensuring no volatility in movement speed, hence maintaining the accuracy of sensor data. Outside the agricultural and biosystems engineering department at Andalas University, rice plants (*Oryza sativa* L) will be lined up using a polybag as a medium, and the sensor will be positioned on the left or right side of the object to enable readings.

2.3.2. Error During Static Condition

Error during static conditions refers to a measurement error that occurs when the tool is at rest or static, i.e., there is no change in speed. Faults occur when manual measurements differ from tool measurements; the accuracy factor may be responsible for these variations in reading (human error) or calibration errors in the planned equipment.

2.3.3.Cutting Width Under Dynamic Conditions

The optimal speed range is between 3,0 and 6,5 kilometres per hour (ASAE Standard, 2009). When measuring the cutting width, the sensor values will be modified with a one-second delay so that readings can be taken quickly due to the status of the moving (dynamic) tool. Use a GPS tracker to determine the movement coordinates of the mini combine harvester for the best results. The GPS tracker will record the coordinates and the cutting width.

2.3.4.Dynamic State Error

Errors occur when the results of manual measurements differ from the results of sensor measurements; these differences in measurement results may result from reading accuracy factors (human error) or technical errors in the field. The cutting width of the mini combine harvester's cutting track can be measured manually during dynamic conditions. On a straight path, the meter can be used for measurement purposes.

2.4.Data Analysis

Statistical data analysis was performed to determine descriptive data from the results of each observation calculated using the average or mean, standard deviation, and coefficient of variation, followed by regression analysis to determine the relationship between sensor readings and manual measurement outcomes.

3. RESULTS AND DISCUSSION

3.1.System Design Results

A 30-centimetre-long iron is utilized to place the automatic cutting width measuring instrument prototype on the mini combine harvester. Iron is a good material for constructing brackets for the sensor holder while measuring the cutting width (cutting width). The brackets will be mounted on the right and left sides of the mini combine harvester's header at 50 cm from the ground. The bracket is installed with size 13 nuts and bolts to allow for its disassembly (plug and play). This study uses a Housing Box to house sensors, control system devices, and an LCD to display the measurement findings. This design employs an ABS plastic 17 x 24 cm housing box. The sensor component will read the distance between the ultrasonic sensor reading and the target to be identified at the left header position (cm) and the right header position (cm). Then, the GPS tracker will read the coordinates of the mini combine harvester's movement per unit time so that the tool's coordinates may be determined when measuring the cutting width. The LCD will display the reading results when the VL53L1X sensor and GPS tracker have measured the cutting width and coordinates. The reading data will also be kept in the database using a WIFI connection and a MicroSD-equipped datalogger (Alfino *et al*., 2020).

3.2.Static Performance Test

Sensor readings (*predicted value*) are obtained from measurements using ultrasonic sensors, both left and suitable. In contrast, the actual measurement results (*true value*) are obtained from a measuring instrument's direct measurements.

a.Left and Right VL53L1X Sensor Reading Accuracy Test

Test the accuracy of the left and suitable sensors using ten types of distance variations from the specified target. The results of the accuracy-test can be seen in Figure 2.

b.Testing the Accuracy of Reading the Cutting Width (cutting width) in Static Conditions

Using a 120-centimetre-long, right- and left-sided 30-centimeter-tall angled iron with 30-centimetre-tall sensors, evaluate the precision under static conditions. Five rice-planted polybags were utilized for the static test (*Oryza sativa L*). The polybags are put parallel to the angled iron, which has been prepared by placing the ToF VL53L1X sensor on the right and left sides. Ten variations of the distance on the polybag are generated by sliding and lowering the number of polybags in the system three times for each distance change. Figure 5 illustrates the static test outcomes for the system design.

Sensors on the right and left will determine the distance to the rice plants (a) and (b) (b). (a) Furthermore, (b) are combined to determine the value of the cutting width. Then, it is decreased by the header width (LH) to yield the cutting width in cm. Figure 3 depicts the accuracy test outcomes for the first, second, and third tests.

Observations were made on the first, second, and third repeats with ten variations in cutting width. The R values obtained were 1, 0.998, and 0.995, respectively. These results indicate that the sensor reading data is less accurate than the distance reading when both sensors are subjected to an accuracy test; this occurs because the wind's field variables create unstable plant movement. However, the accuracy of the reading findings is ensured by the proximity of the regression value to 1. Kim *et al*. (2008)

evaluated the precision of the ToF sensor with an R^2 value of 0.9989. The accuracy test is measured from a distance of 20 to 1300 mm.

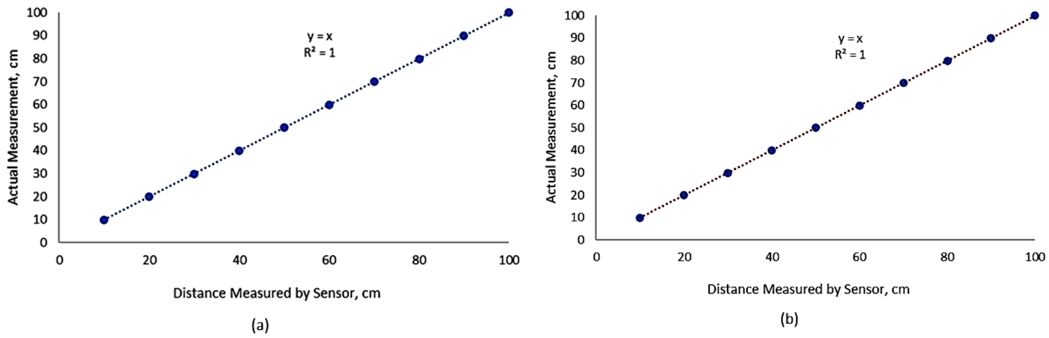

Figure 2. ToF sensor accuracy test graph VL53L1X: (a) Right and (b) Left

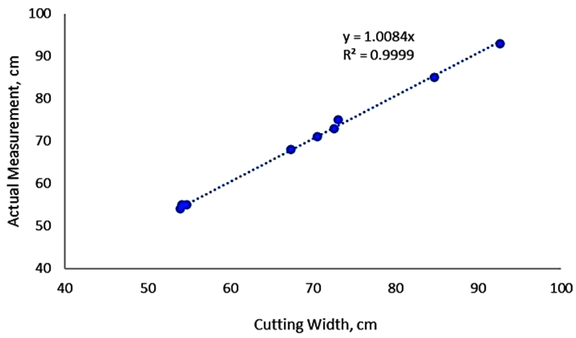

Figure 3. Graph of comparison of actual values of ultrasonic sensor cutting width readings with manual measurement

3.3.Installation and Testing of Control Systems

3.3.1.System Power Requirement

The main component that requires electrical power (supplied from dry battery installed in combine harvester) is the ESP 32. The ESP 32 has an input voltage limit of 3.3 volts to 5 volts. Each *input* and *output pin* requires a current of 40 mA. A total of 8 digital pins are used, namely D4, D5, D18, D19, D23, D26, D33, and D34 which are connected to a voltage of 5 volts. The power required is calculated as *Power* = 3.3 *V* x (0.04 x 8)A = 1.056 W.

3.3.2.Connection to Web Server Database

In this study, the data storage system for measuring cutting width and coordinates uses two types of storage: datalogger-based and website-based.

a. Datalogger Mechanism

This study measures the cutting width using a VL53L1X sensor and a GPS tracker to detect the movement coordinates of the rice harvesting instrument. Following GPS and ultrasonic sensor readings, the data will be transmitted to the ESP32 for processing. The ESP32 will then send the data to the SD Card storage file to execute data logging and store the data. This data logger stores data in.txt or text file format, making it easy to process data with other apps such as Microsoft Excel or Spreadsheet.

b.Real-time Web Monitoring Mechanism

Data received and processed by ESP32 is also shown as tables and graphs on the localhost web. Under how localhost operates, ESP32 will execute the application using the web-server library in order to access the localhost web. After then, programming is performed on ESP32 using one of the web programming languages, HTML, for the localhost web display. Accessing the local-host web requires attaching a monitoring device, such as a laptop or cell phone, to the same network as ESP32. Because the serial monitor is designed to display the IP address for the local host, the local host can be accessed to determine the IP address used to open the web localhost.

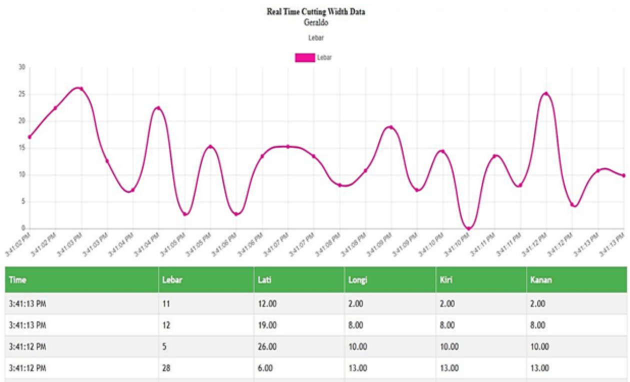

Figure 4. Example of Interface from website

3.3.3.Error in Static Condition

Error during static conditions is the occurrence of a measurement error while the instrument is at rest or static, i.e., there is no change in speed. The sensor reading result (predicted value) in static error measurement is compared to the actual measurement result (true value). The retrieval of data was conducted with ten distance modifications. Each variant was repeated three times. Table 1 displays the results of each data's error analysis in the static test.

Table 1. Error analysis of cutting width measurement (cutting width) in static conditions

Data	*Error* (cm)	*Error* Percentage (%)	Standard *Error*
1	0.40	0.43	0.06
2	0.50	0.70	0.12
3	0.00	0.00	0.39
4	0.40	0.65	0.10
5	0.70	1.03	0.06
6	0.27	0.49	0.17
7	0.40	0.55	0.21
8	0.87	1.58	0.23
9	1.94	2.58	0.61
10	0.37	0.43	0.09
Average	0.58	0.84	0.20

The error rate (cm), percentage error (%), and standard error for the reading of the cutting width (cutting width) during the static test are displayed in the table above. According to the preceding table, the inaccuracy ranges between 0 and 1.94 cm. At the error percentage level, the range is 0 to 2.58 percent. The error value error value is still accepted if it is smaller than 20%. The calculated standard error ranges from 0.1 to 0.61.

In a prior study (Zhao *et al*., 2010), the greatest error value was 4.80 cm, and the average error value was 2.52 cm. Under static conditions, measurements were conducted for one minute with three repetitions. Compared to the error value achieved in prior investigations, the error value obtained in this study is significantly lower; this shows that the cutting width measurement under static conditions can be reasonably accurate.

3.3.4.Real-time Cutting Width Measurement Results

The utilized sensors are two units of the VL53L1X ToF sensor as a distance measurement sensor that measures the cutting width and a GPS module to determine the coordinates change of the mini combine harvester during the harvesting process. The VL53L1X ToF sensor is fitted left and right on the header of the Kubota DC 35 mini combine harvester for monitoring the cutting width under dynamic situations. A bracket constructed of iron measuring 30 cm in length and 13" in diameter is used to attach the sensor to the header. In the meantime, the housing box is positioned near the operator for convenient viewing. The cutting width was measured under dynamic conditions on three rice field demonstration plots in Padang City.

After the cutting width data and tool movement coordinates have been collected, the data will be processed using the ArcGIS application. The kriging approach will examine the cutting width measurement findings regarding statistical zone data. Kriging is a stochastic estimation technique comparable to Inverse Distance Weighted (IDW), which uses a linear combination of weights to estimate values between data samples. Error and confidence are quantified through Kriging. This method uses a semivariogram to describe the spatial differences and values between every pair of data samples. On three rice field demonstration plots measuring 19.4 m x 24.1 m for plot 1, 16.4 m x 20.8 m for plot 2, and 22.6 m x 24.8 m for plots 2 and 3, the cutting width was determined under dynamic settings (Figure 4).

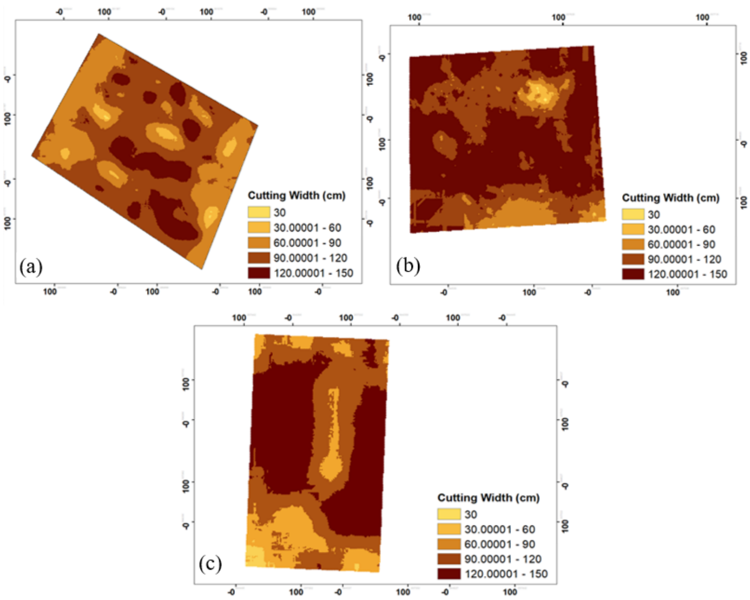

Figure 4. Kriging demonstration: (a) Plot 1; (b) Plot 2; (c) Plot 3

According on the needs of the kriging map, the displayed results can be modified. As depicted in Figure 4, the kriging results are separated into five class distributions depending on various cutting widths. The distribution of the cutting width for each plot is given in Tables 2, 3, and 4.

Table 2. Distribution of cutting width in Plot 1

No	Cutting Width Group（cm)	Area（m²)	Percentage of Area（%)	Grade
1.	0 - 30	0.39	0.08	very low
2.	30.001 - 60	14.50	3.08	low
3.	60.001 - 90	163.81	34.84	moderate
4.	90.001 - 120	214.37	45.59	high
5.	120.001 - 150	77.15	16. 41	very high
	Total	470,22	100	

Table 3. Distribution of cutting width in Plot 2

No	Cutting Width Group（cm)	Area （m²)	Percentage of Area (%)	Grade
1	0 - 30	0.17	0.05	very low
2	30.001 - 60	3.45	1.07	low
3	60.001 - 90	26.57	8.26	moderate
4	90.001 - 120	111.65	34.71	high
5	120.001 - 150	179.78	55.90	very high
	Total	321.62	100	

Table 4. Distribution of cutting width in Plot 3

No	Cutting Width Group（cm)	Area（m²)	Percentage of Area （%)	Grade
1	0 - 30	0.01	0.00	very low
2	30.001 - 60	7.42	1.31	low
3	60.001 - 90	97.24	17.10	moderate
4	90.001 - 120	213.29	37.51	High
5	120.001 - 150	250.67	44. 08	very high
	Total	568.63	100	

The harvesting operation of plot 1 generated the greatest percentage of cutting width in the fourth class (90.001 to 120), which was 45.59 percent. In the fifth class (120.001 to 150 cm), the percentage of the maximum cutting value that the tool is capable of represents 16.41%. The smallest cutting width is 0 and 30 cm, with 0.08%. The overlap of the mini combine harvester, which repeatedly chops at the same location, is responsible for the lowest cut value. Whereas this can be caused by the difficulty of the point being harvested and the small amount of land, narrow land can cause the overlap of the mini combine harvester to be greater due to the equipment's size not being proportional to the area of land being harvested.

The second demonstration plot yielded the greatest proportion of cutting width within the range of 120.001 to 150 cm, at 55.90%. The smallest cutting width was discovered in the 0 to 30 cm range with a percentage of 0.05%. For example figure 3, the most significant proportion of cutting width (44.08%) is found in the range of 120.001 to 150 cm, while the smallest percentage is in the first class (0 to 30 cm) at 0.00%.

In addition to being caused by overlap and narrow land area, low cutting values can also be caused by sensor noise. Data obtained while the mini combine harvester is not harvesting while the measurement system is active or powered on, or data with values that do not correspond to the real harvesting scenario, are examples of noise data. Consequently, the read data are noise data. Based on the gathered data and the results of Kriging performed on the ARCGIS application, it can be determined that the mini combine harvester's rice harvesting operation involves a degree of cutting variability. Operator judgments can induce variability in the cutting width due to abrupt changes in movement speed and overlap, resulting in substantial inaccuracies. This is common when crop plugging issues occur in the header, harvesting at the end of the bund or headland, and pausing to unload the harvested grain (Schuster, 2016).

3.3.5.Error in Realtime Cutting Width Measurement

The cutting width error of a mini combine harvester is a sensor measurement error that occurs as the mini combine harvester travels to harvest. During dynamic error measurement, the sensor reading result (predicted value) is compared to the actual measurement result (true value). Mini combine harvester data is retrieved manually using a meter by measuring the width of the cutting trail from the track or tracks crossed. Observations of dynamic inaccuracy are limited to straight tracks due to the nature of straight tracks. The mini combine harvester harvests the full cutting width. From the database-sent time and coordinates, sensor readings are obtained. Each demonstration plot collects five cutting width measurements when the mini combine harvester operates at its maximum cutting width. The above equation calculates error, percentage, and standard error—table 5 displays the error analysis results for each demonstration plot in the field test (dynamic).

Table 5. Analysis of cutting width measurement errors in mini combine harvester

Plot	Error (cm)	Error Percentage (%)	Standard Error
1	2.69	1.53	1.60
2	3.05	2.18	2.15
3	2.32	1.59	1.60
Average	2.68	1.76	1.78

The error rate in measuring the cutting width under dynamic conditions, such as while the mini combine harvester is harvesting, is presented in the table above. The average inaccuracy in the three demonstration plots is 8.687 cm or 6.35 percent. The obtained error, particularly in plot 1, is rather substantial. Light intensity is the primary component creating a significant erroneous value. According to the datasheet for the VL53L1X ToF sensor, the light intensity can impact the sensor's readings. Insufficiently robust brackets that cannot tolerate vibrations from the mini combine harvester also contribute to measurement inaccuracies.

Compared to the research conducted by Putri *et al*. (2022) on the measurement of cutting width using the US-100 ultrasonic sensor, which error value of 8.36%. This study obtained a lower value (6.36 %), suggesting that the VL53L1X sensor can perform measurements more effectively.

4. CONCLUSIONS

Based on the research, it is possible to infer that the cutting width measurement instrument based on the ToF VL53L1X sensor can measure cutting width accurately during static and dynamic tests.

1. The reading of the VL53L1X ToF sensor under static settings is close to the real value, as indicated by the R^2 values 0.995.
2. With an average error value of 6.36 percent, the cutting width measurement control system utilizing the VL53L1X ToF sensor can function effectively.
3. Both the database system utilizing a Web-Server and the database system utilizing a datalogger can operate efficiently with the database system that has been created.
4. The cutting width (cutting width) variation is depicted on the map developed using the kriging interpolation method and ArcGIS for five cutting width class ranges. With a proportion of 55.90%, the average cutting length is between 120 and 150 cm.

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