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Cut Crop Edge Detection Using a Laser Sensor

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Cut Crop Edge Detection Using a Laser Sensor

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Abstract. *An off-the-shelf low cost laser sensor was tested and evaluated both in laboratory and field conditions. The sensor identified the angular and straight edges of the laboratory test surface and replicated the straight edge profile with an error of 4%. In field conditions, the sensor identified three types of cut crop edges (wheat, alfalfa and corn) and replicated distinct shapes (triangle, curved and rectangular edges). The sensor was tested at two sensor path offset distances and three tractor/sensor speeds (3.2, 6.4 and 9.6 km/h). In all test runs the sensor detected the cut-crop edges. Standard deviations and RMSE values in determining the actual cut-crop edges for the entire field test were within 210 cm and 13 cm respectively. The sensor performed the best in the case of wheat cut-crop edge where the RMSE was 4.2 cm (sensor path offset = 1m, speed 3.2 km/h) and performed the worst in the case of alfalfa cut-crop edge where the RMSE was 16.7 cm (sensor path offset = .30 m and speed 9.6 km/h).*

Keywords. Laser sensor, offset distance, cut-crop edge, RTK-GPS

Introduction

Harvester yield monitoring systems have been widely used since the mid 1990's. These systems typically utilize some form of force impetus sensing device to predict mass flow rates of grain through the harvester based on a calibration procedure. Additional information such as grain moisture content, cut-width, and field position is also gathered during the harvesting process. This data is subsequently used for estimating: accumulated mass, dry bushels of marketable grain, harvest rates, and generating yield maps for field management purposes. Although these systems have performed well over the years, some limitations have been identified which can contribute to significant errors. Producers are currently forced to manually input the cut-width of the harvester head when harvesting partial cut-widths. This is not as difficult when harvesting row crops such as corn or sorghum which are often planted in 30 inch rows. However, when harvesting crops such as wheat or soybeans which are often planted in 7.5 in rows, producers are much less likely to correct for the actual cut-width of the harvester. This can lead to a significant source of errors for yield estimates and can also create errors when yield maps are generated from the harvest data. Ideally, a yield monitoring device would incorporate a cut-width sensor to continually correct for the actual yield and location of the crop being harvested. Reitz and Kutzbach (1996) utilized two ultrasonic sensors for cut-width determination, although no accuracy information was reported. Missotten et al. (1996) utilized two ultrasonic sensors for cut-width measurement. They reported a relative accuracy of 5% based on tests in wheat. Sudduth et al. (1998) utilized both RTK GPS and ultrasonic sensors to assess cut-width. They concluded the ultrasonic sensor worked well in wheat. However, more careful data processing was required when using the sensor in drilled soybeans. Ultrasonic sensors have also been utilized extensively for ranging and tree canopy assessment in orchards (Zaman and Salyani, 2004; Iida and Burkes, 2002; and Tumbo et al., 2001). A critical component for determining the actual cut-width of row crops is the sensing element which identifies the cut-crop edge.

The present study focuses on evaluating an off-the-shelf laser sensor for identifying the cut-crop edge in different types of crops. The laser sensor considered is well established in the manufacturing sector and will be evaluated in both laboratory and field conditions. Validation of the laser sensor in sensing the cut-crop edge will clarify if the sensing methodology has a good potential to be used on harvesting machines for determining the cut-width of the harvested crop in real-time. Further, this sensing methodology may find place in row crop automated guidance systems which require sensing of the cut-crop edge.

Objectives

The main objectives of this study were to

- To evaluate the utility of off-the-shelf low cost laser sensor for sensing the cut-crop edge
- To test the laser sensor in laboratory and field conditions
- To evaluate the performance of laser sensor in sensing the cut-crop edge in three types of crops (Corn, Wheat and Alfalfa).
- To monitor the response of the laser sensor at different speeds and different offset distances.

Materials & Methods

An off-the-shelf low-cost laser sensor which is predominantly used in the manufacturing sector is considered for this study. The laser sensor used was O1D100 manufactured by Ifm-efector, Inc (Exton, PA) which had a sensing range of 20 cm to 1000 cm

Sensor Evaluation & Calibration

The sensor operates on the time-of-flight principle; the travel period for reflected light returned from the object is directly proportional to distance. The light source is a 4.1 mW, class 2, laser with a wavelength of 650 nm pulsed at 1.3 ns. This sensor is priced at $350 (U.S.) retail and has an accuracy of 3.5 cm within the operating range of the sensor. Calibration of the sensor was accomplished by aligning the sensor perpendicular to a solid surface target at distances ranging from 50 cm to 900 cm in steps of 50 cm. Sensor voltages were averaged over a 5 second period at each distance and plotted as a function of the actual distance. The resulting calibration curve was linear with a coefficient of determination of r^2 =0.999 and can be seen in figure 1.

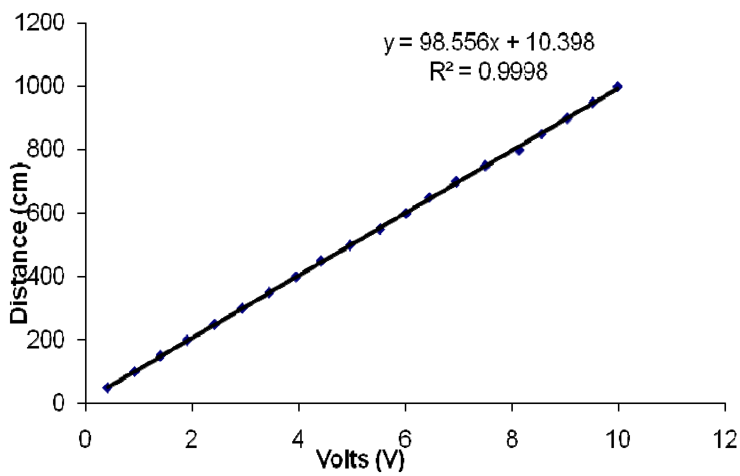


Figure 1. Calibration of the laser sensor

Laboratory Testing

Procedures

The laser sensor was mounted on a rectangular steel bar which in turn was attached to a movable test fixture (fig. 2). The test fixture moved the sensor along the track in a straight line at a constant speed of 0.6 km/h perpendicular to the laboratory target. The laboratory target was made with cardboard which had parallel and nonparallel surfaces with respect to the sensor path. The ranging output d from the laser sensor (LS) was digitized and stored using a 12-bit A/D card at a sampling frequency of 1000 Hz. The sensor was spaced at a distance of 0.50 m from the nearest parallel edge of the laboratory target. The intent was to detect different angled surfaces and reproduce the physical profile. The orientation of the non-parallel surfaces was 27.0^{o}. The laboratory test set up can be seen in figure 2.

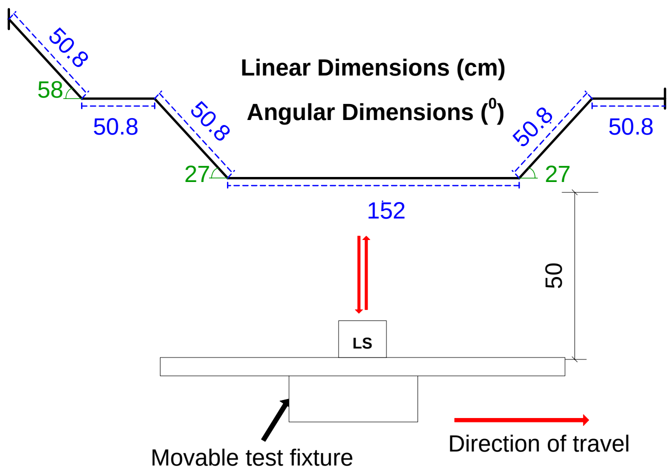


Figure 2. Laboratory test set up

Field Testing

Procedures

The laser sensor setup used for laboratory testing was attached to the mounting bracket (fig.3) on the tractor to provide ranging measurements perpendicular to the direction of travel in the field.

Figure 3. Sensor setup (top-left); Corn cut-crop edge (top-right); Tractor/sensor path in alfalfa cut-crop edge (bottom-left); RTK-Base station (bottom-right)

Cut-crop edges with distinct shapes were created in three types of crops; wheat, alfalfa and corn to evaluate the performance of laser sensors. The sensor path was a straight line and was limited to a constant offset distance for a particular run from the nearest parallel segment of the cut-crop edge. The sensors were tested at sensor path offset distances of one meter and two meter for wheat, 0.3 m and two meter for alfalfa and 0.38 m for corn cut-crop edge. The tractor was driven at speeds of 3.2, 6.4 and 9.6 km/h to at each sensor offset distance. A pole–mounted RTK GPS receiver was used to record the spatial coordinates of the cut-crop edges (wheat, alfalfa and corn) at 1 Hz. RTK-GPS antenna (fig.3) was mounted directly above the sensor to record the actual path of sensors for each test run. The GPS coordinates of the tractor path and the cut-crop edge were projected from decimal degrees to cartesian coordinates to compare sensor response profile to the actual cut-crop edge.

Data processing and filtering

The laser ranging device measurements for all the cut-crop edges were recorded at 1000 Hz and hence there were 1000 measurements corresponding to one set of RTK GPS coordinate acquired from the tractor mounted rover GPS. The RTK GPS coordinates of the cut-crop edge were collected with a pole-mounted receiver moved manually along the cut-crop edge. Data were logged at a frequency of 1Hz. The crop edge profile and tractor paths were rotated with respect to a common reference point on the tractor path to simplify analyses. The origin of the coordinate system was aligned on the tractor path with x-axis oriented along the direction of travel of the tractor and y-axis perpendicular to the direction of travel. Comparison of the sensor's distance output (d) with the actual cut-crop edge profile required interpolation of the x coordinates of the tractor path to equal the x coordinates of the cut-crop edge. The distance output from the sensor can be compared to the 'y' coordinate of the cut-crop edge only if the magnitude of x coordinate on the sensor/tractor path is same as the magnitude of x coordinate on the cut-crop edge.

Fewer GPS coordinates were recorded for the tractor path because of the higher speeds of operation when compared to the number of coordinates recorded for the cut-crop edge. The cut-crop edge data was collected by walking along the track and hence there were two data arrays with different sizes to be compared. Also each GPS coordinate on the tractor path had 1000 laser sensor measurements tagged to it. Thus, Interpolation was done between successive GPS coordinate pairs along the tractor path to obtain unique x-coordinates for each distance measurement recorded from the ranging devices. After interpolation of x- coordinates, to eliminate laser sensor measurements with high magnitudes the data was first clipped using a threshold distance of 700 cm. In addition to clipping, a moving window of size 50 was considered and minimum distance measurement was picked and stored in a separate array along with the corresponding RTK-GPS coordinate. The resultant array from the tractor path was then compared to the RTK-GPS coordinates of the cut-crop edge to match the 'x' coordinates. Finally, a comparison was made between the sensor's distance output (d) and the 'y' coordinates of the cut-crop edge profile using the common 'x' coordinates.

Actual cut-crop edge profiles were compared to the response of laser sensor in each crop. Standard deviation and RMSE of the generated cut-crop edge profiles by the laser sensor were determined and compared at different speeds and offset distances.

Results & Discussion

Lab Testing

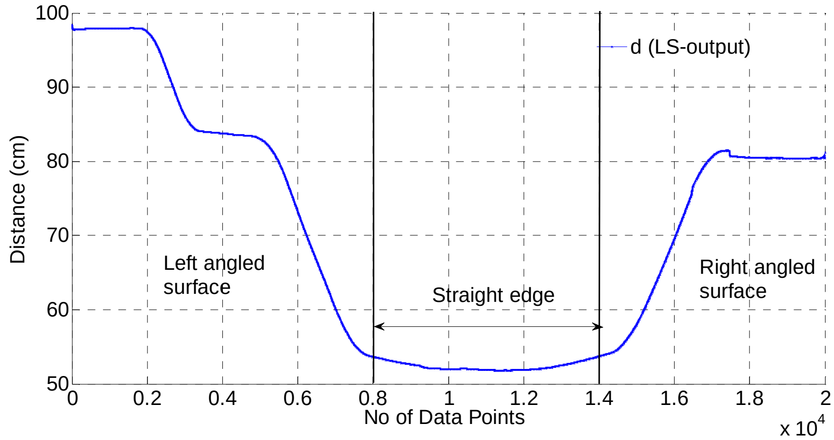


Figure 4. Distance output (d) given by the laser sensor (LS)

The laser sensor was able to replicate the straight edge and the two angled surfaces of the laboratory target surface (fig.4). The sensor determined the profile of the straight edge with an error of 4%.

Field Testing

RTK- GPS coordinates of the cut-crop edge and the sensor path were exported to Arc-GIS to visualize the sensor path and the actual cut-crop edge. A sample shape file consisting of wheat cut-crop edge and the sensor path at an off-set distance of 2 m can be seen in figure 5. Three distinct shapes manually created in the crop; triangle edge, curved edge and rectangular key-ways can be seen in the shape file.

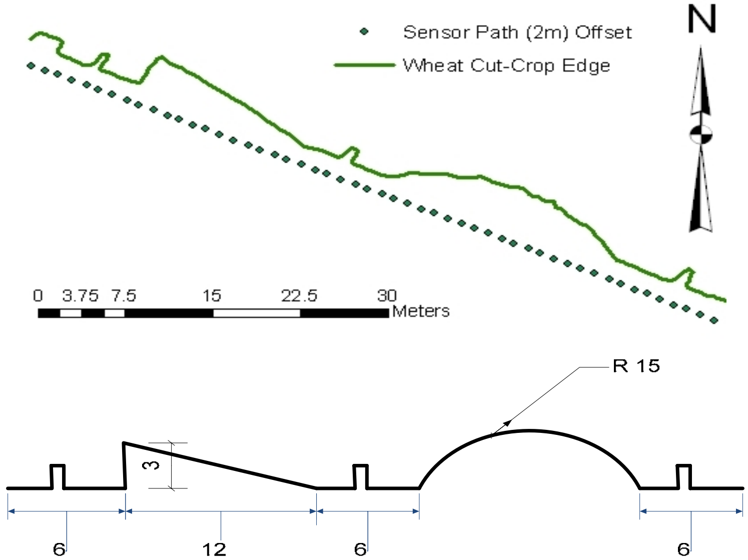
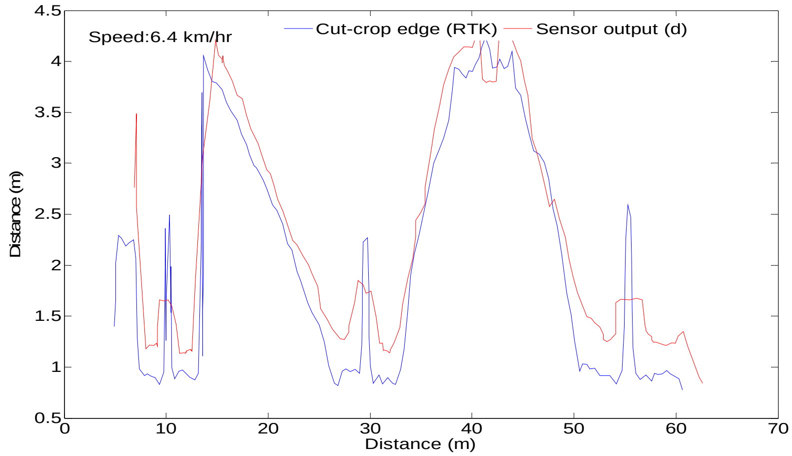
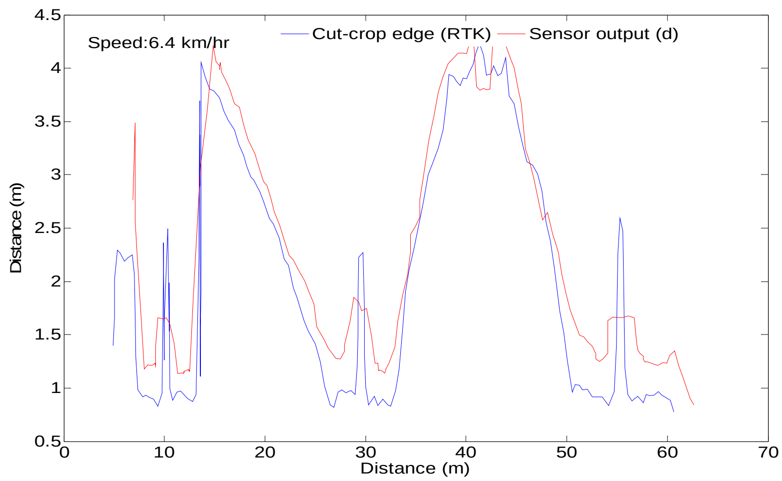


Figure 5. Actual cut-crop edge and sensor path obtained from RTK-GPS coordinates (Top). Diagram showing the dimensions (m) of distinct shapes of the cut-crop edge (bottom)

Type of Crop: Wheat





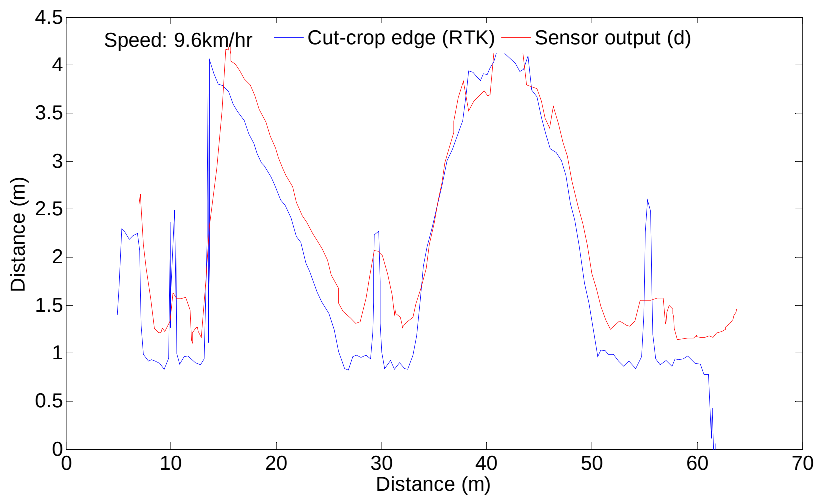


Figure 6. Comparison of sensor output (d) and actual wheat cut-crop edge at speeds of 3.2, 6.4 and 9.6 km/h (sensor path offset – 1 m)

Testing of the laser sensor in wheat cut-crop edge yielded good results. The sensor was able to replicate distinct shapes of wheat cut-crop edge. Sensor output (d) and the actual cut – crop edge were compared in figure 6. at speeds of 3.2, 6.4 and 9.6 km/h. No significant differences were observed upon visual analysis of the comparison of sensor output (d) with the actual cut-crop edge. Standard deviation and RMSE values of the sensor output (d) were calculated and tabulated in table 1 . For both sensor path offset distances of one meter and two meter the standard deviations and RMSE values were observed to increase with increase in speed. The sensor performed the best at 3.2 km/h at a sensor offset distance of one meter . The RMSE between the sensor output (d) and the actual cut-crop edge was 4.2 cm, whereas the standard deviation was 55 cm.

Table 1. Standard Deviation and RMSE of the sensor output (d)

Sensor Speed (kmh^{-1})	1 m Sensor path offset		2 m Sensor path offset	
	Standard Deviation (m)	RMSE	Standard Deviation (m)	RMSE
3.2	0.545	0.042	0.912	0.070
6.4	0.726	0.056	0.782	0.060
9.6	0.930	0.072	0.811	0.063

Type of Crop: Alfalfa

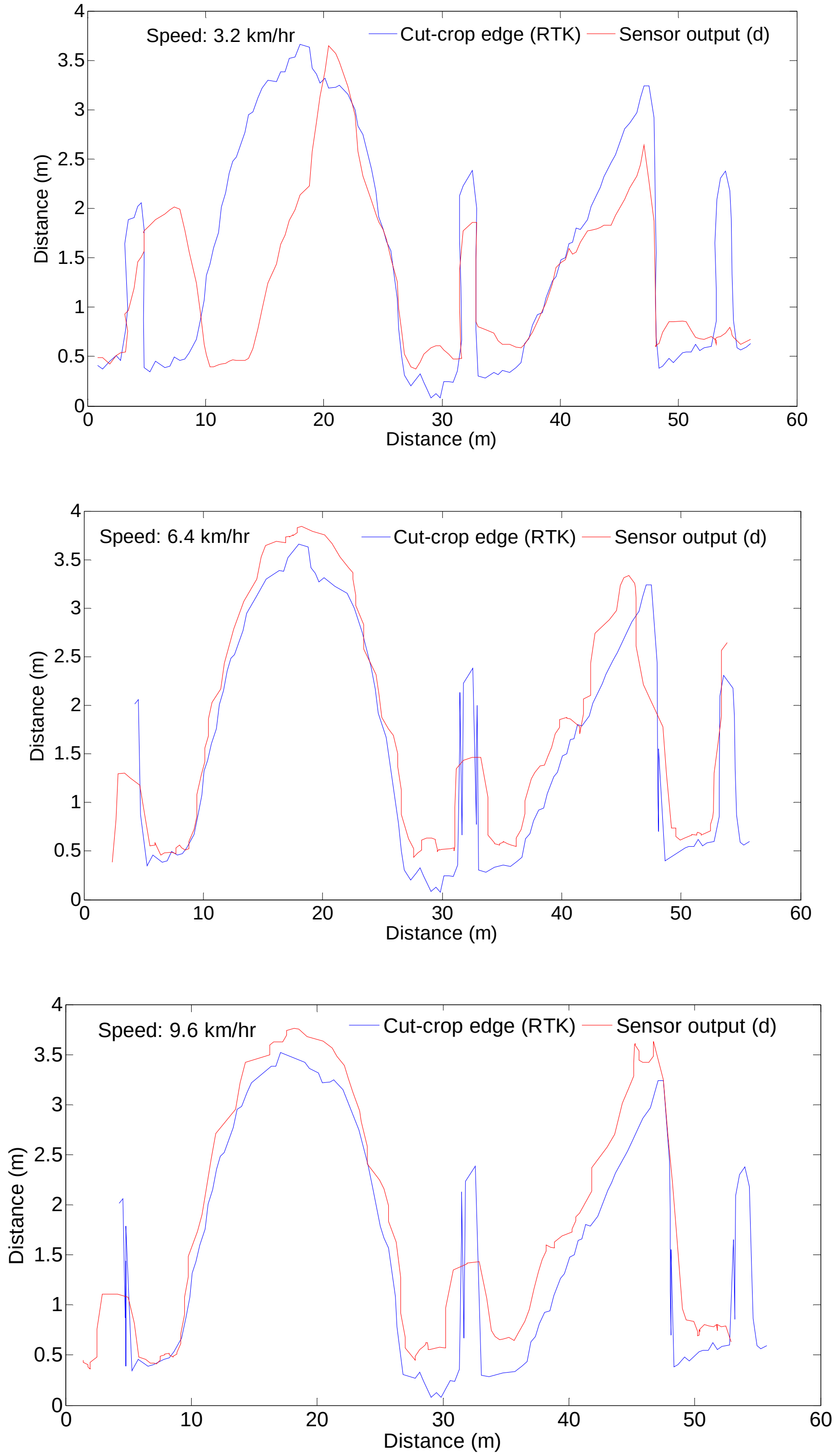


Figure 7. Comparison of sensor output (d) and actual Alfalfa cut-crop edge at speeds of 3.2, 6.4 and 9.6 km/h (sensor path offset – 0.30 m)

In case of alfalfa cut-crop edge the sensor was able to replicate all the distinct cut-crop edge shapes at all speeds of operation. When compared to the wheat cut-crop edge the standard deviations and the RMSE values were higher in case of alfalfa cut-crop edge. The standard deviations and RMSE values increased with increase in speed of operation at a sensor path offset of 0.30 m but. The comparison of actual cut-crop edge and the sensor output can be seen in figure 7. The performance of the sensor was the best at a speed of 6.4 km/hr and two meter offset where, standard deviation and RMSE values were 140 cm and 11.2 cm respectively. In case of two meter sensor offset there was no particular trend in the variation of standard deviations and RMSE values with increase in speed of the tractor

Table 2. Standard Deviation and RMSE of the sensor output (d)

Sensor Speed (kmh^{-1})	0.30 m Sensor path offset		2.00 m Sensor path offset	
	Standard Deviation (m)	RMSE	Standard Deviation (m)	RMSE
3.2	1.695	0.135	1.583	0.126
6.4	2.069	0.165	1.400	0.112
9.6	2.094	0.167	1.612	0.129

Type of Crop: corn

In case of corn cut-crop edge the sensor was tested only at a sensor path offset distance of 0.38 m due to field conditions. The sensor was able to detect the triangle edge, curved edge and the rectangular key- ways. A comparison of sensor output (d) and actual cut-crop edge at sensor path offset of 0.38 m for different speeds of operation is depicted in figure 8.

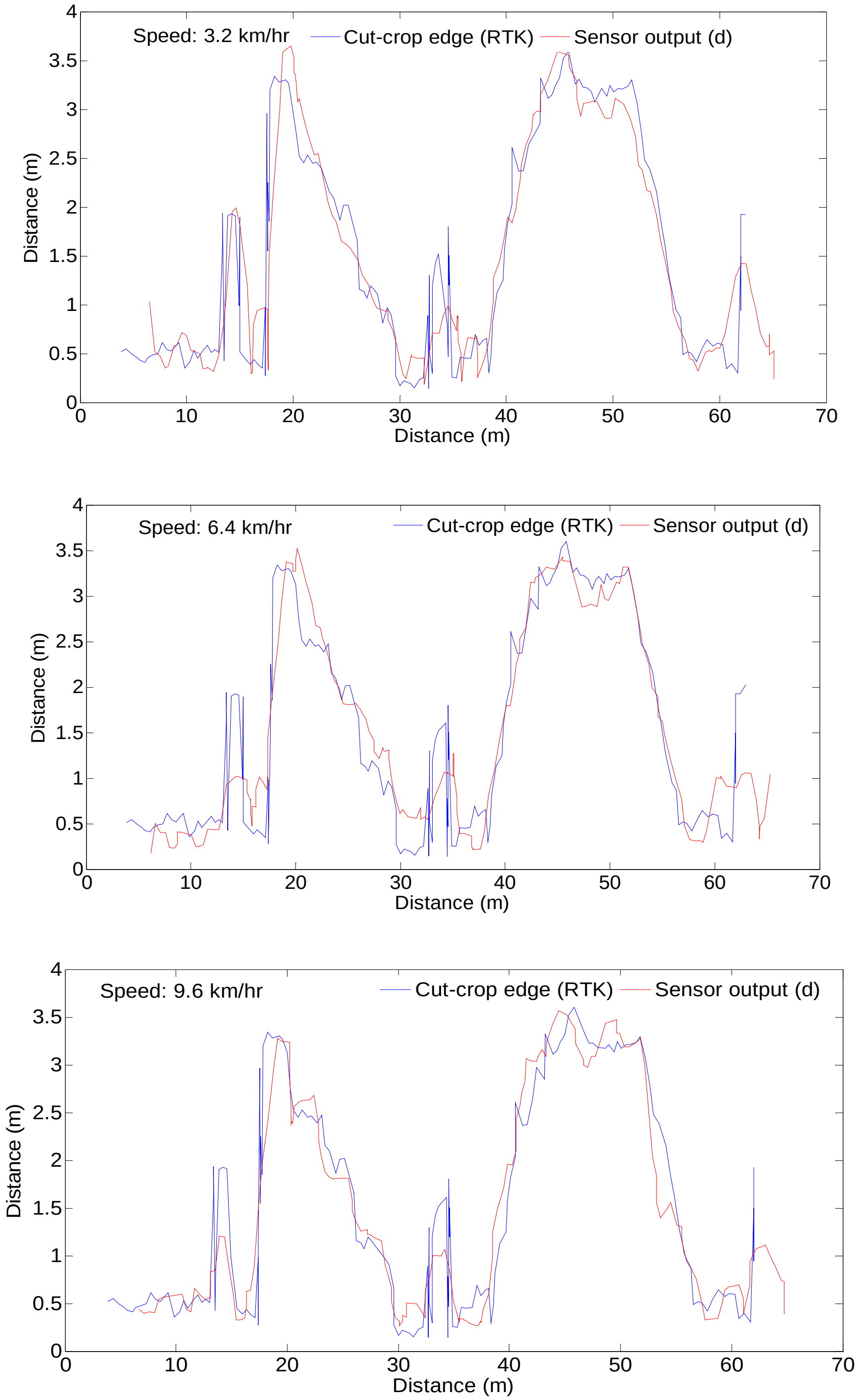


Figure 8.Comparison of sensor output (d) and actual corn cut-crop edge at speeds of 3.2, 6.4 and 9.6 km/h (Sensor path offset – 0.38 m)

Standard deviations and RMSE values were observed to be increasing with increase in speed of operation. The sensor performance was the best at a speed of 3.2 km/h where, the standard deviation and RMSE was 65.7 cm and 4.8 cm respectively.

Table 3. Standard Deviation and RMSE of the sensor output (d)

Sensor Speed (kmh^{-1})	0.38 m Sensor Offset	
	Standard Deviation (m)	RMSE
3.2	0.657	0.048
6.4	0.756	0.055
9.6	0.794	0.058

Conclusion

The sensor identified distinct shapes of the solid test surface in laboratory conditions. The sensor replicated the two angular edges and one straight edge of the target surface. The straight edge of the target was determined with an error of 4%. The sensor setup was tested in field conditions with wheat, alfalfa and corn cut-crop edges at different speeds. The sensor replicated the triangle edge, curved edge and the rectangular key-ways in all the crop edges at speeds of 3.2, 6.4 and 9.6 km/h. Standard deviations and RMSE values in determining the actual cut-crop edges for the entire field test were within 210 cm and 13 cm respectively. The sensor performed the best in the case of wheat cut-crop edge where the RMSE was 4.2 cm (sensor path offset = 1m, speed 3.2 km/h) and performed the worst in the case of alfalfa cut-crop edge where the RMSE was 16.7 cm (sensor path offset = .30 m and speed 9.6 km/h). This study revealed that the low cost off-the-shelf laser has a good potential to be used in crop-edge sensing applications.

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