

ONLINE MEASURING OF GRAIN FLOWRATES AND ITS MEASUREMENT SENSITIVITIES WITH PITCH AND ROLL ANGLES

Renny Eka Putri^{1*}, Azmi Yahya², Nor Maria Adam³ and Samsuzana Abd Aziz²

¹Department of Agricultural Engineering, Andalas University, West Sumatera, Indonesia

²Department of Biological and Agricultural Engineering, University Putra Malaysia, Sedang, Selangor D. E., Malaysia

³Department of Mechanical Engineering, Faculty Engineering, University Putra Malaysia, Sedang, Selangor D. E., Malaysia

* Corresponding author email: renny.ekaputri@yahoo.co.id

ABSTRACT

The goals of this study were to design and create a complete calibration stand with related apparatus for microwave type grain flow sensor calibrations, as well as to investigate the impact of variable field slope (both pitch and roll). Furthermore, this research will quantify the measurement errors of microwave type flow sensor with changing pitch and roll angle positions of the sensors under simulated field conditions. A complete calibration test stand was constructed and instrumented to examine the effect of varying pitch and roll positions on the measurement errors of a microwave solid type flow sensor. Results indicated that measurement errors ranging from 2.50% to 6.82% and 1.80% to 8.86% were obtained by the changing of chute pitch (descending and ascending) and roll angle positions from 1.5° to 4.5°, respectively. Greater measurement errors were found at the low screw auger conveyor speed range. However, the magnitude of errors is within the acceptable margin for any typical wet paddy land topography.

Keywords: Crop Yield Mapping; Microwave Flow Sensor; Flow Sensor Calibration; Flow Measurement Accuracy

INTRODUCTION

Currently, yield mapping is one of most popular tools used in precision farming technology. Previous studies demonstrated that 75% of the fertilizer cost can be saved and its Return on Investment (ROI) can be increased by 26-28% if precision farming is used (Aimrun, *et al.*, 2011; Gassner, *et al.*, 2019; Thornton, *et al.*, 2018). The major drawback of yield mapping is the accuracy of yield map, which is important for the successful implementation of precision farming. Inaccurate yield monitor readings caused errors in the yield maps, which leads to incorrect management decisions.

The accuracy of yield maps is influenced by errors in the yield monitor data, which is used to generate the maps (Grisso, *et al.*, 2002). Earlier research conducted by Yahya *et al.* (2012) had developed a simple,

portable and rugged instrumentation system that could be used directly on any rice combine harvester from different models to monitor measure and record in real time for the harvested crop yield. The use of force impacts flow sensors on combines harvesters for measuring grain mass flow had been widely reported to give low measurement accuracy by previous researchers. It was due to the impact force measurement by the flow sensor which was much dependent on trajectory impact intensity and grain properties of the material. Ideally, all the grains moved by the elevator paddle should hit the surface of the impact plate in order for the sensor to register mass flow rate grain flow. New technology of microwave flow sensor was used to solve the problem of impact-type sensor.

A mild steel chute mounted with microwave solid type flow sensor were located at the end of the clean grain auger in the combine harvester to measure the flow rate of the grain transferred by the auger into the grain tank. The major drawback to the yield measurement instrumentation systems that was earlier developed was the lack of accurate laboratory calibration. Proper calibration investigation must be conducted to improve measurement precision and accuracy prior to development on combine harvester for monitoring crop yield in the field. Quantifying and correcting errors would increase the yield map accuracy, thus improving management decisions based on yield map interpretation (Loghavi, *et al.*, 2008).

Furthermore, several studies have attempted to assess the accuracy of yield monitoring. Yield monitor errors was as high as 18.2% with the combine harvester operating on uphill and 60.7% with the combine harvester on downhill within terrain slopes ranging 6 to 9%. Arslan and Colvin (2002) mentioned a yield monitor of errors of 3.4% when the combine harvester was operating at constant ground speed and errors of 5.2% when the combine harvester was operating at varying ground speeds. Loghavi *et al.* (2008) conducted a laboratory study to stimulate the effect of terrain slopes on the mass flow rate measurements from an impact type sensor by varying the tilting angle of the grain elevator of a test rig. They reported an increase error from 3.5% to 19.4% on the mass flow rate measurements of the grains when the grain elevator tilted from vertical position to 10° forward or representing 17.6% slope downhill. While all of the research focused on impact type grain flow sensor was to determined crop yield.

The objectives of this research were to design and develop a complete calibration stand with its associated instrumentation system for the calibrations of microwave type grain flow sensor and to examine the influence of varying field slope (both pitch and roll). The calibration test stand is capable of testing and evaluating the accuracy of various grain mass flows at same tilt position. Furthermore, this research will quantify the measurement errors of microwave type flow sensor with changing pitch and roll angle positions of the sensors under simulated field conditions.

EXPERIMENTAL SECTION

Design and development of a complete calibration stand

The mechanical components of the calibration test stand shown in Figure 1 include the frame, an auger-type conveyor system and an elbow shaped chute unit. The microwave type flow sensor was installed

to the elbow shape chute unit. The two sides of the bin are sloped at 30° from vertical which is slightly greater than the angle of repose of most grains, in order to facilitate the easy grain flow through the supply bin.

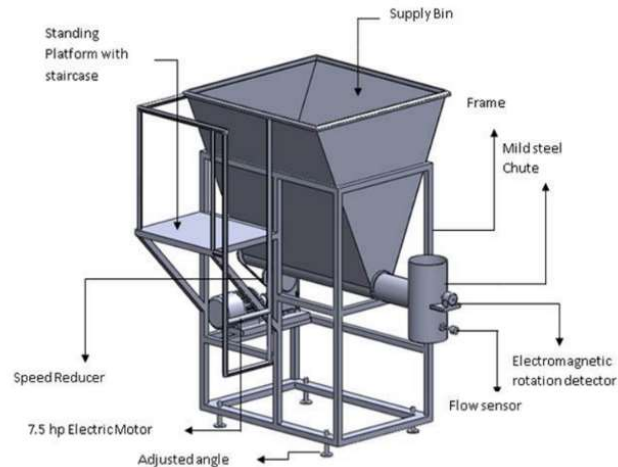


Figure. 1. The calibration test stand

An auger at the bottom of the bin is used to convey the grain from the supply bin to the elbow shaped chute unit. The port of the auger conveyor located under the grain supply tank was covered with a 200 mm diameter concave plate having long slots at both sides along its length. This arrangement relieves the weight of supply tank grain on thereby avoiding potential plugging problems of the conveyor. The auger conveyor was driven by a SO132 Electrim Slinck Variable Speed AC Motor (5.6 kW@1450 rpm) through a double strand chain drive system with interchange sprocket drive sets to give the speed ratios of either 1:1 or 1:2. A VF-8Z Panasonic inverter variable frequency 3 Phase (400v 7.5 kW) was used to vary the motor speed. A GMD worm gearbox having speed reduction of 10:1 was included after the electric motor to provide a further speed reduction to the chain drive system. With the current drive setup, the grain flow through the auger conveyor could be varied from 0 to 5.75 kg/s. Both the electric motor and gear reduction unit were mounted on a special support platform attached to test stand frame at a height of 0.66m from the ground.

Grain from the supply bin flows by gravity into the rotating screw auger conveyor was located below the bin. The rotating screw auger conveyor delivers the grains to the elbow shaped chute unit. The grain in the elbow shaped chute housing drops by gravity into the collection box below. The microwave type flow sensors were installed in opposite directions to each other on the vertical pipe of the chute unit at 150 mm distant from the bottom tip opening of the horizontal pipe of the chute unit. The microwave type flow sensors would register the instantaneous flow rates of grain falling into the collection box.

Data collection technique

The component for data collection and instrumentation system are Panasonic CF-19 toughbook, National Instrument CompactRio 9004 embedded system, D-link DIR-655 router, two microwave type flow sensors. <https://doi.org/10.25077/aijans.v2.i02.45-56.2021>

sensor, and ONO SOKKI MP-810 electromagnetic rotation detector. The detail functions of each component in the developed instrumentation system are summarized in Table 1. Flow rate of grain and elevator speed are factors of interest considered for calibrating the yield monitor in this research. The Panasonic CF-19 toughbook with in-house National Instrument LabVIEW 8.6 software was used to control and display the measured data from sensors. Wireless communication was set up between the embedded system and the toughbook by the use of D-link DIR-655 router and D-link DWA-140 USB adapter. The National Instrument CompactRio 9004 embedded system was used in processing the measured signal from sensors.

It is a portable rugged industrial computer embedded system designed for various field applications. The measured data from the embedded system was wirelessly transferred through the router and received by the adaptor on the toughbook. All the received measured data was stored inside the hard disk of the toughbook and subsequently displayed on-line on the monitor screen. These measured data were then retrieved for the purpose of analysis using Microsoft Office Excel.

Table 1. Functions of components in the instrumentation system.

Name of Component	Function
Panasonic CF-19 toughbook with in-house National Instrument LabView 8.6 software	Controls the receiving, recording and saving the measured data. Displays the measured data.
National Instrument CompactRio 9004 embedded system with NI 9221 I/O module	Controls the acquiring, conditioning, and processing the measured signal from sensors.
D-link DIR-655 router with 3 D-link ANT24-0700 antennas and a D-link DWA-140 USB adapter	Provides wireless communication between the embedded system and toughbook.
SWR SolidFlow microwave type flowsensor and evaluation unit	Measures the flow of clean grain dropping from the levelling auger.
ONO SOKKI MP-810 electromagnetic rotation detector	Measures the rotational speed of the levelling auger.
Power distribution box	Provides the input power with AC to DC converter.
Panasonic VF-8Z Frequency Inverter	Vary the auger speed via the electric motor

The microwave type flow sensor calibration

The SWR Solid Flow microwave type sensor with measurement range of 3 to 20,000 kg/h at ± 2 to 5% accuracy, working at a maximum transmitting power of 5 mW, was used to measure the grain flow in a free fall condition during calibration test. The flow sensor was positioned with elbow. During the calibration test, the sensor was connected to input channel AI2 of the NI 9221 I/O module on the embedded system, and the measured reading were wirelessly transferred to the nearby Toughbook for displaying on its monitor and then storage on the hard drive. The linear regression function with Microsoft Excel was employed to analyse the laboratory calibration data.

The respective calibrations equations are were used in the LabVIEW to convert sensor output to the physical parameters of interest. The auger was driven by a 7.5 hp variable speed AC electric motor through double speed chain drive system with the speed ratio of 1:1 and 1:2 interchangeable sprockets. A frequency inverter was used to vary the motor speed. Another gearbox with ratio of 1:10 was used to reduce the motor speed to the desire auger speed. A Panasonic VF-8Z frequency inverter was also used to vary the auger speed to operate between 45 to 149 rpm by changing the setting of the frequency inverter at increments of 5 Hz from 30 to 50 Hz range. These tests were replicated three times at each speed auger and the data was used to construct a calibration curve.

For each test, an empty collection box was placed directly below the elbow shaped chute unit to collect the falling grains at a measured time period. The collected grain was weighed using a Sartorius GMBH Gottingen digital electronic balance. The total mass of collected grain was recorded. Collection time was measured with a stop watch. The actual flow rates of grain are calculated from weight of grains accumulated after deducted weight of box divided collection time. A minimum stabilization period of 5 seconds after switching on the motor to attain steady-state flow was practiced before data logging was initiated for another 5 seconds. The overall procedures were repeated three times and finally a graph of actual mass rate against measured sensor voltage, and the graph of actual grain mass flow rate against auger speeds were plotted. The same test was repeated at different sensor positions for determining the most accurate sensor positioning in measuring the flow rates of the free-falling grain. The combination of two different sensor orientations (i.e 180° and 315°) and three different sensor extrusions (i.e 7 cm, 8 cm and 9 cm) for 180° orientation and 3 cm, 5 cm and 7 cm for 315° orientation) were used in this test. The test was repeated three times per each sensor orientation-extrusion treatment combinations. Graphs of sensor voltage from sensor against mass flow rate were plotted. The best combination of sensor orientation-extrusion was selected based on the computed R^2 value of the fit regression equations.

The microwave type flow sensor responses under different simulated terrain conditions

Extensive simulated tests were conducted to examine the effects of longitudinal and lateral field topography variations (i.e pitch and roll slopes) on the accuracy measurement of the sensor. The test stand was initially set to tilt in the longitudinal positions and then in the lateral positions to stimulate effects of pitch angle and roll positions on the measurement of the flow rate by the sensor. A total of four different chute orientation positions (ascending pitch, descending pitch, right roll and left roll), three different chute orientation levels (i.e 1.5°, 3.0°, and 4.5°) within the conveyor auger speed of 44 rpm to 149 rpm were involved in these investigations with the instrumented calibration stand set-up. Yap *et al.* (2006) claimed that measurements on the pitch and roll angles from a combine during a harvesting operation in a typical rice field at Tanjung Karang, Selangor Malaysia were around 0.1° to 1.5° and 0.1° to 2°, respectively. Based on such claimed, this experiment was conducted under a simulated field condition with pitch and roll slope angles ranging from 0 to 4.5°. Adjustments to the provided level screws on the four legs of the calibration

test stand were made accordingly to get the required pitch or roll angle for the test and digital Inclinometer was used to measure the slope angle.

The aim of the tests was to determine the effect of the sensor measurements with changing pitch or roll angles. The auger conveyor speed was varied to operate from 45 to 149 rpm by changing the setting of frequency inverter. These tests were carried out at pitch and roll slopes of 1.5°, 3°, and 4.5°. A series of repeatable test were conducted under steady state grain flow measurement and simulated changes in ground slope. In each test, the flow cycle was repeated three times. A statistical analysis was performed on the experimental data obtained using Statistical Analysis System (SAS) software. Analysis of Variance (ANOVA) was conducted to determine the significance of the chute position, level and auger speed on voltage reading of measured flow sensor. Also, Dun-can's Multiple Range Test was conducted to compare the means of the treatments.

Accuracy test

The aim of the test was to quantify the accuracy and precision of measured grain flow rate using flow sensor. The plots of real time sensor flow rate against the actual measured flow rate by the conventional weighting method are presented. The error was specified base on R^2 value of the plot of real time flow rate reading by the sensor against the actual measured flow rate by the conventional weighting method.

RESULTS AND DISCUSSION

Sensor calibration

The microwave type flow sensor was successfully calibrated. Next, sensor was calibrated under dynamic calibration mode at two different sensor orientations (i.e 180° and 315°) and three different sensor extrusion positions on the chute unit. The test was conducted to investigate the best combination of sensor orientation and extrusion positions on the chute unit for the measurement of flow rate of the falling grain. Distance of sensor extrusion was decided based on distance of free falls paddy to the tip of the sensor. The profile of the falling rice was closed to the sensor tip with sensor orientation at 315° than sensor orientation of 180°. Thus, sensor extrusions of 7 cm, 8 cm, and 9 cm were used for sensor orientation of 180° and sensor extrusions of 3 cm, 5 cm and 7 cm were for sensor orientation of 315°. The results showed that the best sensor position is on totally flat ground at 180° orientation and 8 cm extrusion of the chute cross section with R^2 value 0.9400. The microwave type flow sensor indicated good voltage output respond to varying screw auger conveyor speed at sensor orientation of 180° than at sensor orientation of 315°. From observation, the sensor orientation 180° was sensitive to the flow measurement because the extruded tip of sensor was at position not too far from the trajectory profile of the falling grain. Other observation, having two sensors operating together in the chute unit did not improve the flow measurements because of the possibility of the interruption on the transmitted microwave signals. The following calibration equations were obtained for the microwave type flow sensor:

$$GF = 0.914V + 0.926 \text{ with } R^2 = 0.9400 \dots\dots\dots(1)$$

where,

GF = Corresponding grain flow rate, kg/s

V = Measured voltage by microwave solid type flow sensor, V

SWR SolidFlow Microwave Type Flow Sensor Responses under Different Simulated Terrain Conditions

The measurement response of the microwave flow sensor was investigated under simulated terrain conditions. The simulated terrain conditions considered for the tests included combinations of four chute orientation configurations (i.e ascending pitch, descending pitch, left roll and right roll) and three chute orientation levels (i.e 1.5°, 3.0°, and 4.5°). Each chute orientation configuration and orientation levels were tested within the screw auger conveyor speeds of 44 to 149 rpm range for sensor orientation of 180° and extrusion position of 8 cm on the chute unit (Fig. 2). Pitch positions at level -4.5°,-3.0° and -1.5° called descending pitch, while pitch positions at level +4.5°, +3.0° and +1.5° called ascending pitch. In addition, roll positions at level -4.5°, -3.0°, -1.5° called left roll, while roll positions at level +4.5°, +3.0°, and +1.5° called right roll.

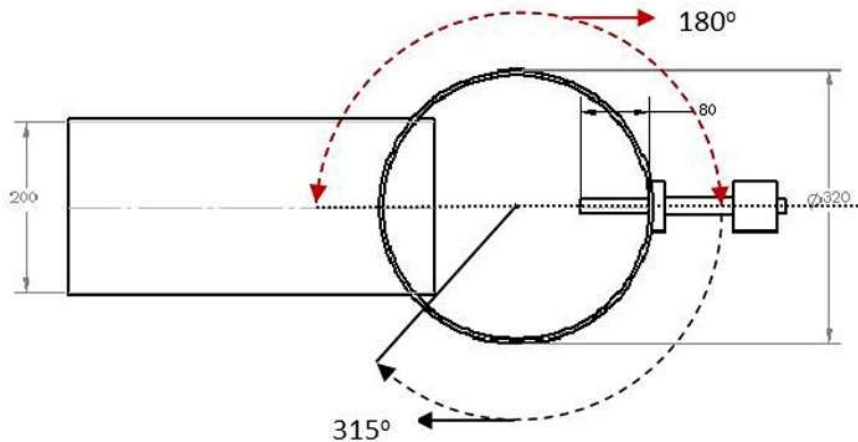


Figure. 2. Top view of SWR SolidFlow microwave flow sensor position

The first 5.0s of data collection within the stabilization duration were not recorded in the instrumentation system. Data were taken after five seconds or when the readout of voltage was believed to have achieved a steady state condition. The result described that for all chute orientation configurations, levels and the screw auger conveyor speed were found to be in significance on different voltage reading of flow sensor at 10% significant level. The mean square of grain flow as affected by chute orientation configuration, chute orientation level and screw auger conveyor speed are compared in Table 2. Loghavi and Almaee (2009) also found tilting the elevator system significantly affected mass flow sensor accuracy.

Duncan test shows the significant different of the voltage reading of microwave flow sensor within the chute orientation (i.e., ascending pitch, descending pitch, right roll and left roll). The different of mean comparison voltage between ascending pitch and descending pitch was 28.67%, while percentage difference of mean comparison voltage between left roll and right roll was only 2.25%. It could be concluded that the mean voltage reading of microwave type flow sensor for right roll and left roll are nearly same, so that system accuracy is independent of the roll angle.

Table 2. Analysis of variance for the chute orientation configuration, level and screw auger conveyor speed on the mean voltage readings from flow sensor

Source of Variation	DF	Sum of Square	Mean Square	F Value	P Value ^{a)}
chute orientation configuration	3	30.1293051	10.0431	773.56	<.0001 ***
chute orientation level	2	1.6002664	0.8001332	61.63	<.0001 ***
chute orientation configuration*	6	12.2281705	2.0380284	156.98	<.0001 ***
chute orientation level					
Screw auger conveyor speed	9	447.548815	49.727635	3830.23	<.0001 ***
Chute orientation configuration*	27	19.0762292	0.7065270	54.42	<.0001 ***
Screw auger conveyor speed					
chute orientation level *Screw auger conveyor speed	18	7.8565985	0.4364777	33.62	<.0001 ***
Chute orientation configuration*	54	10.5828467	0.1959786	15.10	<.0001 ***
chute orientation level *Screw auger conveyor speed					

*Significant at 10% significant level or 0.1 probability level. **Significant at 5% significant level or 0.05 probability level. ***Highly significant at 1% significant level or 0.01 probability level

On the contrary, the mean voltage reading of microwave flow sensor for difference screw auger conveyor speed exhibited two trends. The low screw auger conveyor speed range (44 rpm to 75 rpm) exhibited less variation in mean voltage reading than for high-speed screw auger range (89 rpm to 149 rpm). Moreover, the sensor reading variation for the high screw auger conveyor speed was seven times greater than the low screw auger conveyor speed range. In addition, at low screw auger conveyor speed range, there is no significant different between 52 rpm and 59 rpm. The voltage output of microwave flow sensor indicated increasing of screw auger conveyor speed. It could be concluded that microwave flow sensor exhibits low sensitive at low screw auger conveyor speeds. The voltage reading value were almost the at all speed within the low-speed auger range (44 rpm to 75 rpm).

The response of voltage reading of the sensor was different with the difference of sensor position orientation at different speed auger (Table 3). It shows equations and R² values of relationship voltage of

sensor reading are against flow rate. The voltage reading of microwave flow sensor on descending pitch angle is excellent with regression coefficients closed to 1.0. It is the effect of total grain quantity in the elbow chute near the tip of the sensor and also gravity of paddy. Then, the lowest accuracy was at ascending pitch angle position ($R^2 = 0.7470$), because the density of paddy dropped not full. The results show voltage reading of right roll angle and left roll angle are same, which is indicated by the R^2 value was almost the same 0.8700 and 0.8820, respectively. It can be concluded that the effect of the angle slope between right and left roll was the same.

Table 3. Equation for every condition at tilled position.

No.	Chute orientation configuration	Equation	R^2
1.	Pitch ascending	$GF = 1.051V + 1.179$	0.7470
2.	Pitch descending	$GF = 0.941V + 0.818$	0.9050
3.	Roll right	$GF = 1.018V + 1.01$	0.8700
4.	Roll left	$GF = 0.985V + 1.037$	0.8820

Grisso *et al.* (2008) noted that yield monitor calibration has a significant impact to the yield monitor accuracy. Calibration equations for microwave flow sensor was created using the whole data from the chute position (ascending pitch, descending pitch, right roll and left roll) and all levels of orientation (1.5°, 3° and 4.5°). However, low auger speed data was emitted in the calibration test, due to observation in the field indicating majority instantaneous flow rate data were collected in the high-speed range. The equation to describe the flow rate trend for the voltage sensor reading is as follows:

$$GF = 0.665V + 2.364 \quad \text{with} \quad R^2 = 0.876 \quad (2)$$

where,

GF = Grain flow (kg/s)

V = Measured voltage by microwave solid type flow sensor, V

Accuracy determination under controlled laboratory conditions

Accuracy tests were developed to compare the real-time grain flow measurements by the microwave flow sensor against the average grain flow measurements by weighing accumulated grain. Accuracy tests were conducted in three elbow chute orientation configurations (i.e., ascending pitch, descending pitch and roll), the three chute orientation levels (i.e., 1.5°, 3°, and 4.5°) and different screw auger conveyor speed with the range of 44 RPM to 75 RPM for low speed and the range of 89 RPM to 149 RPM for high auger speed. There were errors described in three parts, namely; error in low speed, error in high speed and total error. Computation for total error was made based on the compilation of data in high speed and low speed.

Pitch analysis

Pitch angle analysis was conducted into two parts, namely ascending pitch and descending pitch. Pitch angles were obtained by adjusting the frame support feet from angles 0° to -4.5° and 0° to 4.5° , respectively. The positive angle represents uphill travel of combine harvester (ascending) while negative angle represents downhill travel of combine (descending). Results showed that there was an incremental error will change pitch. The lowest error was at slope 1.5° and the highest error was at slope 4.5° with error magnitudes of 5.18% and 6.82%, respectively. However, error magnitudes within low screw auger conveyor speed range were higher than for the high screw auger conveyor speed range. At low screw auger conveyor speed ranged, the magnitudes of errors are from 8.18% to 12.15%, as compared magnitudes of errors of 2.06% to 12.74% at the high screw auger conveyor speed range.

Conclusively, ascending pitch for both screw auger speed range (i.e., low and high screw auger conveyor speeds) shows an increase of error at higher angles with expectation of the low screw auger conveyor speed at 4.5° level. By increasing angle, error increased due as rice fell closer to the tip sensor at both low and high screw auger conveyor speeds. The higher error in low screw auger conveyor speed as compared to high screw auger conveyor speed was due to the effects of the amount total grain quantity in the chute which was near the tip of the sensor. However, during the lowest screw auger conveyor speed tests, the mass flow of grain not great. Ascending itch had greater errors compared to descending pitch. The total error range for ascending pitch was from 5.18% to 6.82%.

Unlike ascending pitch, descending pitch error decreases with increasing levels of both speeds (both low and high screw auger conveyor speed). The lowest error was at slope of 4.5° and the highest error was at slope of 1.5° with the errors of 2.50% and 3.68%, respectively. Similarly, with descending pitch, ascending pitch showed higher error in low screw auger conveyor speed range. The error range for low screw auger conveyor speed for descending pitch ranged from 1.20% to 5.40%, while for high screw auger conveyor speed the error range from 0.15% to 4.82%. Overall, the total error range for descending pitch was from 2.50% to 6.82%.

Descending pitch had lower errors compared to ascending pitch. Most likely the error results from the variation in position as grain pass the tip of sensor. For ascending pitch, the proximity of the grain flow to the sensor tip was closer compared to descending pitch. Fulton *et al.* (2009) reported yield monitor errors as high as 18.2% with the combine harvester operating on uphill (ascending pitch) and 60.7% with the combine harvester operated downhill (descending pitch) within terrain slopes ranging 6 to 9%. However, Loghavi *et al.* (2008) conducted a laboratory study to simulate the effect of terrain slopes on the mass flow rate measurements from an impact type sensor. This is done by varying the tilting angle of the grain elevator of a test rig. They reported there was an increment errors ranging from 3.5% to 19.4% on the mass flow rate measurements of the grains when the grain elevator was tilted from vertical position to 10° forward or representing 17.6% slope downhill. Yap *et al.* (2006) claimed that the pitch angle of paddy field in Malaysia ranged 0.1° to 1.5° . Based on this information, the instrumentation system used on board with a combine harvester showed errors of approximately from 2.50% to 3.68%. These errors were obtained from the

accuracy tests, which showed ascending pitch errors at level 1.5° was 5.18%, while for descending pitch, the error was found to same level of 1.5° was 3.68%. These errors were found to be acceptable for rice yield monitoring in Malaysia.

Roll analysis

Roll angle was indicated as a reference in the travel direction of combine harvester during operations. The results showed that the error increased as there was an increasing roll level, therefore, the lowest error was found at the roll level of 1.5° at 1.80% and the highest error was at 4.5° with 8.86%. To be more specific, the error at low screw auger conveyor speed was higher than the error at high screw auger conveyor speeds. The range of error was from 1.16% to 7.24% for low screw auger conveyor speed and 1.39% to 2.68% for high screw auger conveyor speed. It was supported by Arslan and Colvin (2002) mentioned that during the combination of harvester travel forward and backward, the combination speed does give errors in yield monitoring. Furthermore, Yap *et al.* (2006) mentioned that the roll level of rice field in Malaysia was from 0.1° to 2°. Compared to the accuracy test of yield monitor the instrumentation system, error will not exceed 1.8 %for most of situation encountered when harvesting in Malaysia. In addition, by combining all data and using the average flow rate value at each level of roll, it can be concluded that errors were found at 1.81% to 3.48%, and 3.76% pitch and roll levels

CONCLUSION

A calibration test stand was built and used to successfully evaluate the accuracy microwave flow sensor from 0 to 5.75 kg/s, and also to quantify the accuracy of the sensor for real-time measurement of grain flow under a simulated laboratory condition. The result indicated that the accuracy of this microwave type flow sensor was excellent ($R^2 = 0.9400$) when pitch and roll angles of zero. The simulated combine harvester going downhill or uphill has a significant effect on flow rate readings of the sensor with chute position, level and auger speed. Flow rate measurement errors ranging from 5.18% to 6.82% with ascending pitch from +1.5° to +4.5° and measurement errors ranging from 2.50% to 3.68% with descending pitch from -1.5° to -4.5°. Concurrently, measurement errors ranging from 1.80 % to 8.86%, respectively. Generally, these measurement errors increased with ascending slopes and increasing roll angles. The errors were found to be acceptable for rice yield monitoring in Malaysia. Proper calibration could improve measurement precision and accuracy prior the development on a combine harvester for monitoring crop yield in the field

ACKNOWLEDGEMENTS

The author also wants to thank to students for assistance in carrying out the research.

CONFLICT OF INTEREST

The authors have no conflict of interest.

REFERENCES

- Aimrun, W., Amin, M.S.M., Yahya A. 2011. Comparison of Precision Farming and Conventional Practices for Fertilizer Management in Malaysian Paddy Fields. Proceedings of the 4th Asian Conference on Precision Agriculture, Obihiro, Japan.
- Gassner, A., Harris, D., Mausch, K., Terheggen, A., Lopes, C., Finlayson, R and Dobie, P. 2019. Poverty eradication and food security through agriculture in Africa: Rethinking objectives and entry points. Outlook on agriculture. 48. 309-315. 10.1177/0030727019888513.
- Thornton, P., Dinesh, D., Cramer, L., Loboguerrero, A.M and Campbell. B. 2018. Agriculture in a changing climate: Keeping our cool in the face of the hothouse. Outlook on Agriculture.
- Grisso, R.D., Jasa, P.J., Schroeder, M.A., Wilcox, J.C. 2002. Yield Monitor Accuracy: Successful Farming Magazine Case Study. Applied Engineering in Agriculture. **18(2)**: 147–151.
- Yahya, M. M. Isa, and S. Abd. Aziz. 2012. Portable Wireless Yield Monitoring System for Rice Combine. Paper Presenter at the International Conference on “Agricultural and Food Engineering for Life”, Putrajaya.
- Loghavi, M., Ehsani, R., Reeder, R. 2008. Development of a Portable Grain Mass Flow Sensor Test Rig. Computers and Electronics in Agriculture; 61(2):160-168.
- Arslan, S., T. S. Colvin. 2002. An Evaluation of the Response of Yield Monitors and Combinesto Varying Yields. Precision Agriculture. **3**: 107-122.
- Yap, Y.K., Yahya, A., Jamuar, S., Ruslan, R., Nordin, L., Halid, M., Ninomiya, S. 2006. Design and Development of Rice Combine Harvester Instrumentation System for Crop Yield and Field Performance Mapping. AFITA 2006: The Fifth International Conference of the Asian Federation for Information Technology in Agriculture, Bangalore, India. 301-311
- Loghavi, M. and Almaee, M. 2009. Development of a Laboratory Test Stand for Grain Combine Yield Monitoring.
- Fulton, J., Sobolik, C., Shearer, S., Higgins, S and Burks, Thomas. 2009. Grain Yield Monitor Flow Sensor Accuracy for Simulated Varying Field Slopes. Applied Engineering in Agriculture. 25. 15-21. 10.13031/2013.25425.