Optimation of Crawler Speeds Measurement Using Inductive Proximity for Autonomous Combine Harvester

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Abstract. This paper proposes an optimal method for measuring the crawler rotational speeds of an autonomous combine harvester by the inductive proximity sensor. It mounts an inductive sensor on each wheel so it can detect the metals and the holes on the crawler drive gear. Detection of metals and holes continuously forming a cycle with a particular frequency. The crawler speed is determined by counting the number of cycles at one second as a frequency. The crawler speeds are proportional to the frequency. However, there is another way of measuring crawler speed by counting the cycle period. This research compares measuring methods for the crawler speeds using frequency and period to determine the optimal method. The results of the experiment show that measuring crawler speeds by periods is more accurate than frequency.

Keywords: speed measurement, inductive proximity, autonomous combine harvester.

1. Introduction

Reliable and accurate speed measurement is important in vehicle field guidance like an autonomous combine harvester. The position and orientation information of the vehicle is essential for autonomous guidance [1]. One option to get the position and orientation of the vehicle is using RTK-GPS. From the series of two-position data could estimate the orientation and the speed of the vehicle [2]. However, GPS alone has the same characteristics, such as blockage, multipath error, low update rate, and latency, which may limit its application in vehicle positioning systems [3]. The heading angle of the autonomous vehicle is not accurately detected using GPS only [4].

The autonomous combine has two crawler systems to move on the paddy field, which has two differential drive crawlers. Monitoring and measurement rotational speed for each crawler could estimate the combine orientation because the different left and right crawler speeds make the change of combine direction. Integrated this method with RTK-GPS can improve positioning performance. Accurate crawler low-speed detection is essential to estimate the combine speed and orientation. The incremental rotary encoder position could estimate an ordinary revolution per minute (RPM) measurement of the shaft. This method measures the change in the angle by counting the pulses produced in a counting period [5]. In this study, an inductive proximity sensor is mounted on each crawler to detect the gear wheel rotation speed of the crawler. The sensor then converts the proximity of the metallic tooth gear into a binary signal [6]. A literature review shows that counting the pulses produced does not apply to a low-resolution encoder, of which the pulses are not frequently. An alternative way is to count the time intervals between two pulses.
This research aims to get a reliable method to measure the crawler speed of an autonomous combine harvester. The comparing better way to estimate the rotational speed of crawler by counting the pulses produces and the time intervals of two pulses.

2. Materials and methods
This study used an autonomous vehicle modification from a mini two rows head-feeding combine harvester shown in figure 1a. An inductive proximity sensor is mounted on each crawler, which detects the crawler gear rotation. The diameter of the gear is 16 cm, with the number of gears is 5. The position of the inductive proximity has been set, so it will be on only when the tooth of the gear facing the inductive proximity sensor faces, as shown in figure 1b. The frequency and time interval of the production pulse were counted using a microcontroller.

![Figure 1. (a) The autonomous combine harvester which used, (b) Position of the inductive sensor](image)

Table 1 shows the specification of the inductive sensor. The proximity sensor’s output is connected to the Arduino external interrupt pin through a voltage-reducing circuit. If the gear tooth is facing the sensor surface, the sensor will output a voltage of 12 V. This voltage must be reduced into 5 volts which equals binary 1 before connected into the Arduino pin. The amount of binary pulse produced by the inductive proximity sensor is then counted in the one-second interval as the rotation frequency of the tooth gear. When the external interrupt pin of Arduino detects the input 1 in a binary number, the Arduino program will add the number of pulses until the end of counting intervals. The measurement result of the pulse frequency is displayed and recorded on a personal computer connected via serial communication of the Arduino, as shown in figure 2.

| Item                  | Specification                  |
|-----------------------|--------------------------------|
| Sensing distance      | 15 mm ± 10%                    |
| Standard sensing target | 45 x 45 x 1 mm (iron)          |
| Operation voltage     | 12 – 24 VDC                    |
| Response frequency    | 200 Hz                         |

The second method, crawler speed, was estimated using a time interval between two pulses as a period. In this method, the time interval of the output pulse was calculated using micros function of the
Arduino IDE. It returns the number of microseconds since the Arduino board begins running and goes back to zero after 70 minutes. The Arduino microcontroller with 16 MHz clock pulse that uses in this study was able to produce a resolution of four microseconds. When the Arduino’s interrupt pin detects the input 1 in a binary number, the Arduino program will read the pulse time interval in microseconds unit and reduce it with the number of microseconds took before. The deviation of this number became the time intervals between two pluses and estimated the rotational crawler speed.

![Arduino and laptop](image)

**Figure 2.** Data acquisition diagram

3. Results and Discussions
The Crawler speed measurement test uses two methods, counting the amount of pulse in one second as a frequency and the second counting intervals between two pulses as a period. The crawler speed was tested using the rotational interval between 15 rpm to 50 rpm. The recorded data was used to find the calibration equation. The result of the first measurement method is drawn in figure 3. It is shown that the minimum rotation speed of the 15.5 rpm was detected as 1 Hz or one pulse in one second while the maximum rotation speed of the 51 rpm was detected as 5 Hz both for the left and right crawler.

![Graph](image)

**Figure 3.** Counting the frequency of the output pulse

Based on figure 3, it concluded that the speed change in 7.1 rpm equals the change value one pulse in one second. It is essential considering the differential vehicle model changes the orientation of the vehicle's model direction based on the speed difference between the left and right tracks, as shown in
figure 4, and the change direction orientation angel of the vehicle can be calculated using equation 1 [1]. Based on equation 1 is calculated using the diameter of the gear drive combine harvester 16 cm and width of the left-to-right track distance 94 cm as well as the difference of speed 7.1 rpm so it can cause the angle changes about 2.3°.

\[ \psi = \tan \left( \frac{v_d}{W} \right) \]  

where :  

\[ v_d = v_r - v_l \]

The result of the second measurement method is drawn in figure 5. It shown that the minimum rotation speed of 15.5 rpm was detected as 82554 microseconds time interval while the maximum rotation speed of 51 rpm was detected as 232400 microseconds time interval both for the left and right crawler. It means that a change speed of 1 rpm can represent 16709 microseconds. This shows that the period measurement is better than the frequency of the pulse. The second measurement method produced more accurate measurement results which able to differentiate rotation speed less than 1 rpm while the first measurement method only able to differential rotation speed as the multiplication of 7.1 rpm.

![Figure 4. Differential steering two differential drive vehicle model](image)

![Figure 5. The time interval for one period of output pulse](image)
The output pulse of the inductive proximity sensor at the minimum speed (15.5 rpm) is shown in figure 6. The average frequency of the pulse is about 1.2 Hz, and the average period is about 0.82 seconds. The graph also shows that at any time the output pulse will be read as 1 Hz and at the other time will be read as 2 Hz. Measurement by using the first method will only produce an integer value. Therefore, the resolution is low. By measuring the period, it can measure in a microsecond so that it can measure with higher resolution.

![Figure 6. The output pulse of the inductive proximity sensor at 15.5 rpm](image)

After the calibration equation was implemented into the measurement system than it was validated using the same interval of the tooth gear rotational speed. The validation result is shown in figure 7. The graph shows that the second measurement method (time interval method) is more accurate than the first measurement method.

![Figure 7. The validation test](image)

The performance values of both methods are calculated using the root-mean-square error (RMSE) values. The RMSE is an excellent method to present the model performance, which is calculated using equation 2 [7]. Based on figure 6, the RMSE value of the frequency method is 4.2 rpm, and the period method is 1.3 rpm. Besides, the most significant absolute error in the frequency method is 11.8 rpm, while the period method is 3.1 rpm.

\[
RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} e_i^2}
\]  

So far, several autonomous agricultural vehicles that perform farming operations, such as the autonomous tractor [8], and the autonomous rice transplanting [9] using multiple sensors. These
autonomous vehicles navigate using an RTK-GPS, gyroscopes, and compass for accurate navigating of the autonomous agricultural vehicle. Besides the above sensors, the new develop speed measurement sensor can be collaborated for calculating the vehicle orientation when the GPS data is lost.

4. Conclusions
From this study, it can be concluded that the measurement of the crawler speed of autonomous combine harvester by counting the period of the inductive sensor pulses is more reliable than using frequency. The validation test has shown that the RMSE error of period method is smaller than frequency; there is 1.3 rpm and 4.2 rpm. In addition, the largest absolute error in the frequency method is 11.8 rpm, while the period method is 3.1 rpm.

5. References
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