System Identification and Steering Control Characteristic of Rice Combine Harvester Model

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Abstract. This study is a preliminary research of rice combine harvester trajectory. A vehicle model of rice combine used crawler with differential steering. Turning process of differential steering used speed difference of right and left tracks. This study aims to learn of rice combine harvester steering control. In real condition, the hydraulic break on each track produced the speed difference. The model used two DC motors with maximum speed 100 rpm for each tracks. A rotary encoder with resolution 600 pulse/rotation was connected to each DC motors shaft to monitor the speed of tracks and connected to the input shaft of a gearbox with ratio 1:46. The motor speed control for each track used pulse width modulation to produce the speed difference. A gyroscope sensor with resolution 0.01° was used to determine the model orientation angle. Like the real rice combine, the tracks can not rotate to the opposite direction at the same time so it makes the model can not perform the pivot turn. The turn radius of the model was 28 cm and the forward maximum speed was 17.8 cm/s. The model trajectory control used PID odometry controller. Parameters input were the speed of each track and the orientation of the vehicle. The straight line test showed the controller can control the rice combine model trajectory with the average error 0.67 cm.

1. Introduction
A combine harvester is a versatile machine designed to harvest a variety of grain crops. The grain crops are harvested from the field to deliver clean grains, collected in the machine tank and discharge periodically for transportation and further processing or storage. The following main crops are harvested using combine harvesters: wheat, rice, barley, soybeans, and corn. The combine harvester combines all technological operations of grain crop harvesting: cutting and gathering of the plants, grain threshing and separating, and grain cleaning and collecting in the combine tank [1].

The rice combine harvester operated in the field requires a higher operator skill and performance level. Operator has to simultaneously control the travel speed and direction of the combine harvester while adjusting the height of the header after considering numerous parameters [2]. Combine harvester operating on paddy field under unfavorable environmental conditions such as the dust particles, noise, and vibration from the machine increase the operator’s fatigue. The fatigue reducing operator’s focus which can decrease the productivity and efficiency. An automatic system is needed to help operator to control the combine. The autonomous guidance system performs unmanned harvesting and can be used to replace all field operations performed by operator [3]. The autonomous guidance system overcomes the lack skill and performance operator and gains more work stability and productivity. The system allows traveling fast and accurately along the target path.

In recent years, numerous sensors, methodologies, computational algorithms, and other supporting technology evolution cause development of autonomous agricultural machine still interested.
automation methodologies have been proposed and developed for an autonomous guidance system because it depends on the field environment, operation, and supporting technologies [4]. The different method can be different for the sensors, navigation, algorithm, and equipment. All of the methods have been developed the same purpose to get high accuracy and replace all operator function.

To make the combine can run automatically, follow the reference path, it is necessary to know the control system characteristics of the steering in operating the combine. Characteristics that needed to be known, there is how to turn, rotate, maximum speed, orientation change, turning radius, and how to control it along operated [5]. Learning characteristics of combine harvester steering control is difficult using the real combine. On real size is needed more space and energy to do this process. A model is created for reducing those needs which is built smaller than the real combine with the similar steering type. The steering type of combine will be used to developed automatic trajectory system is crawler type with two tracked wheel differential drive. This study is a preliminary research of rice combine harvester trajectory to learn how the rice combine harvester steering control.

2. Materials and methods
This study started from the measurement of combine harvester dimensions, especially on the moving parts. After that, determination of model dimensions had been based on market availability and space requirements for the placement of electronic components such as microcontrollers, sensors, drivers, batteries, and motors. The finished design model manufactured and installed of electronic components. After the model that been made, then functional test was done to determine the suitability of each component function. In addition, calibration of the sensors was also used. In order to control the model carried out the design of controllers and navigation. Finally, trajectory test was done the model to follow the path of reference.

A vehicle model of combine was built using crawler with a differential drive like the real combine. The model main frame was made of 3 mm thickness aluminum plate. Design of vehicle model can be seen in figure 1.

![Figure 1. Design of combine vehicle model.](image)

The model used crawler as wheel drive which used plastic material. Comparison between model and real can be seen on table 1.

| Parts                  | Model | Real  |
|------------------------|-------|-------|
| Track material         | Plastic | Iron steel |
| Track length (cm)      | 35     | 112   |
| Sprocket diameter (cm) | 5      | 16    |
| Length between tracks (cm) | 30  | 94    |
| Track width (cm)       | 4.5    | 25    |
Most of the model parts used the scale of 1:3 to approach the real condition and adjust availability parts of the model. In real condition, the speed difference on combine crawler is produced by the hydraulic brake on each tracked wheel. The model used two DC motors with maximum speed 100 rpm for each track. Each DC motors speed was controlled using pulse width modulation to produce the speed difference. Like the real rice combine, the tracked wheels of model cannot rotate in the opposite direction at the same time so the model does not do pivot turn.

The model trajectory control used odometer PID controller on equation 1. Parameters input were the speed of each tracked wheel and the orientation of the vehicle.

\[ u = k_1 e_n + k_2 \int e_n \, d\alpha + k_3 \frac{d e_n}{d\alpha} + k_4 e_\phi + k_5 \int e_\phi \, d\alpha + k_6 \frac{d e_\phi}{d\alpha} \] (1)

where:
- \( u \) : ratio of difference and total speed
- \( k_1, k_2, k_4 \) : PID constant
- \( e_n \) : position error
- \( e_\phi \) : orientation error

Dead reckoning navigation was used to determine the model position. The next position was calculated from the initial position, velocity, orientation, and time. Determination of velocity as well as position on x, y coordinate was calculated using equation 2, 3, and 4.

\[ \dot{s} = R \dot{\alpha} = R \left( \frac{\dot{\theta}_1 + \dot{\theta}_2}{2} \right) \] (2)
\[ \frac{dx}{d\alpha} = R \cos \phi \] (3)
\[ \frac{dy}{d\alpha} = R \sin \phi \] (4)

where:
- \( R \) : Wheel radius
- \( \phi \) : Orientation angle

![Figure 2](image_url)

**Figure 2.** Vehicle relative position, position error, and orientation.

Position error of model from trajectory path is marked \( e_n \) and orientation error is marked \( e_\phi \) as shown in figure 2. That errors can be determined using equation 6 and 7.

\[ e_n = \sqrt{\Delta X^2 + \Delta Y^2} \] (5)
\[ e_\phi = \phi_r - \phi \] (6)

A rotary encoder with resolution 600 pulse/rotation was connected to each DC motors shaft to monitor the speed of crawler and connected to the input shaft gear box with ratio 1:46. Orientation of the vehicle was determined using a gyroscope sensor with resolution 0.01°. A microcontroller was used
as the main controller. The microcontroller collected the data from sensor, proceed and determined speed of each track. The motor driver receives the pulse modulation signal from the microcontroller to drive the DC motors. The data from rotary encoders, gyroscope, and the speed of each track was recorded using SD card module for data analysis. Control system of the model can be seen in figure 3.

![Control system of the combine harvester model.](image)

**Figure 3.** Control system of the combine harvester model.

Steering control characteristic consists of time response each track, time response turn orientation, turn radius, and path following test. Characteristic of time response was used to develop PID equation especially tuning PID process. One of the methods tuning PID use Ziegler-Nichols method which was used in this study. The turn radius and steering control process characteristic as long as the model goes along path trajectory.

![Time response motor.](image)

**Figure 4.** Time response motor.

### 3. Results and Discussion

Time response test was done for each track motors. The motors were drive to maximum speed from the rest position. It can show the time of each motor to reach maximum speed in figure 4 shows the result of time response test for each motor. The motors have different response although the same motor in different direction. Right motor have maximum speed 16 cm/s for counterclockwise and 17 cm/s for clockwise direction as well as left motor have maximum speed 20 cm/s for counterclockwise and 19 cm/s for clockwise direction. That difference can be caused by motor manufacturing or track setting.
The speed difference between right motor and left motor cause the model can not trajectory on straight line path without controlled.

In figure 5 shows time response test result for orientation change. One of the motors rotated at maximum speed and the other did not rotate. It was done alternately for right motor and left motor to know the orientation change versus time. The orientation change average for CW direction is 4.1 °/s and CCW direction is 4.2. There is little difference because left motor speed higher than right motor.

![Figure 5. Orientation change.](image)

Based on time response data, the PID controller equation was developed using Ziegler-Nichols method. In spite of all the advances in controller method over the 50th years ago, the PID controller still exists.

The Ziegler-Nichols rules was a very influential rule for tuning PID controller. This method developed tuning rules by simulating a large number of different processes and correlating the controller parameters with features of the step response. The first determined the proportional constant then integral and differential constant [6]. The PID constants was obtained for position error $k_p = 0.5$, $k_i = 0.2$, $k_d = 0.5$ and for orientation error $k_p = 0.1$, $k_i = 0.15$, $k_d = 0.01$. The simulation test for P equation ($k_d$ and $k_i = 0$), PD equation ($k_i = 0$), and PID equation can be shown in figure 6. In simulation test, the model was programmed to reach the straight line target path with distance 15 cm beside of target path.

![Figure 6. PID equation simulation test.](image)
When position error of combine model was too large, the model approached sharply then slowly horizontal. From the test was known that the P controller had oscillation around the target path but the PD controller and PID controller seen can approach smoothly. Nevertheless, the root mean square error (RMSE) of the PD larger than PID on stable condition. The RMSE error of the PD is 0.65 cm and the PID is 0.07 cm. So that the PID controller is ideal to control this model moving wherever the moving approach in short time and less overshoot so that the constants are used.

![Approaching test](image)

**Figure 7.** Approaching test.

Approaching test was done to know how the model can reach the target reference path using the controller. In figure 7 can be seen the model approaching from the right path (FRP) and for the left path (FLP). On FRP there is the little overshoot after the model reaches the reference path but on FLP can be seen after the model reaches the reference path little back away. The approaching test can be compared with figure 6 the PID simulation test that shows the approach too but on simulation. The real test on approaching test shows a similar pattern.

![Trajectory straight line test](image)

**Figure 8.** Trajectory straight line test.

In figure 8 shows the result of trajectory straight line test on real condition and simulation. The test was done using average speed 17.8 cm/s on the floor and sampling time 0.1 s. Average error on real condition is 0.67 cm and maximum error 0.98 cm while on simulation the average error is 0.26 cm and the maximum 0.35 cm. In this study was used the odometry method to determined the model position. This method can estimate the position from the speed and direction data. Odometry assume that wheel revolution can be translated into linear displacement relative to the floor. There are several error sources that fit into two categories, systematic errors and non-systematic errors. The systematic errors consist of
unequal wheel diameters, misalignment of wheels, uncertainty about the effective wheelbase, limited encoder resolution, and limited encoder sampling rate. The non-systematic errors consist of travel over uneven floors, travel over unexpected objects on the floor, as well as wheel-slippage [7]. The trajectory straight line test can be seen in figure 9.

In turning test the model was turned by one of track moved maximum speed and the other not moved. In order to turn left, the right track moved forward and the left track did not move as well as vice versa. The turn radius can be determined by ordered the model to make a circle turn. Result of this test, the turn radius of the model is 28 cm.

Figure 9. Straight line test in real condition.

4. Conclusions
From this study, it can be concluded that system identification and steering control characteristics should be done to control the combine model, and then can be summarized as follows: (1) The combine model can turn based on the speed difference on each track; (2) The greater speed difference of each track make the turn radius will be smaller; (3) The response time indicates the time required by the track to reach ordered speed. It also affects the turning response; (4) The steering control of model can use PID odometry based on traveling speed of each track and orientation change; (5) Based on the simulation and real test shows this method can make the model trajectory reference path.

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