Research on Ground Profiling Control of Combine Harvester Based on the Symmetric Algorithm

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Abstract. Combine harvester is an important part of agricultural modernization, and the function of the header is more important. The header is mainly composed of a transmission device, cutter, and reel. In the process of practical application, the harvest efficiency of different types of the combined cutting machine is much higher than that of manual harvesting. In this paper, a ground profiling sensing mechanism is designed by building a dynamic model. The results show that: the ground profiling sensor mechanism of combine header based on the symmetric algorithm can truly reflect the agricultural terrain data, and provide data support for the action of digging shovel and improve the profiling accuracy of the combine.

1. Introduction

In recent years, with the development and steady progress of agricultural industrialization, China's agriculture gradually presents the characteristics of transforming from decentralized operation to large-scale and industrialized operation. In this context, how to transform agricultural combine harvesters and enable them to complete agricultural production tasks more effectively has become the focus of attention in the current agricultural field. Therefore, many scholars have studied the ways to improve the harvesting efficiency of the agricultural combine harvester. The stripper can effectively improve the work efficiency of the harvester and reduce the loss of grain waste, they analyzed the power consumption of the header harvester and pointed out that as an important core component of the harvester before cutting[1]. Based on Linux-2.6.28 kernel, combine harvester can display header height and other dynamic information in real time on the upper man-machine exchange interface, so as to improve the degree of agricultural automation. they had studied the electro-hydraulic proportional control system and found that the ultrasonic sensor as a distance sensor can effectively control the height of the harvester header[2]. The adaptive header height adjustment system uses the way of unilateral infrared reflection for physical mapping and finally realizes the height measurement through the sensor. Under the action of the adaptive header height adjustment system, the header of the combine can control the height at will, and the maximum height adjustment error is 2cm, and the error of crop height detection device is less than 2cm [3]. Using angle sensors and displacement sensors they calculated the height of the header, it is proved by experiments that the structure of the ground profiling control system of the combine header is simple, and the header height error is not more than 12 mm, which can well meet the farming requirements of the combine[4].

China is faced with the problems of an insufficient labor force, high unit production cost, and low mechanization level, which hinders agricultural development[5]. Therefore, the paper optimizes the ground profiling control system of combine header, to improve the efficiency of the combine, and finally improve the level of agricultural mechanization.
2. Establishment of dynamic model

As shown in Figure 1, when header ABCD passes through, The power provided by MP and NQ of hydraulic cylinders on both sides are FM and FN respectively. It is also known that the angle between A and B is, the angle between and is, and the ground height collected by the sensor is Z1 and Z2.

![Figure 1. Dynamic Model of Combine Header](image)

By analyzing the dynamic model of combine header in Figure 1, it is found that when the header of combine moves around AB, the dynamic equation of header plane rotation can be obtained as follows:

\[
(F_M + F_N)l_s \sin \alpha - \frac{1}{2} m g \sin \theta - k_i \dot{\theta} = J_i \ddot{\theta} \quad (1)
\]

\[
(F_M + F_N) \frac{t}{2} \sin \alpha \cos \beta - k_s \dot{\beta} = J_s \ddot{\beta} \quad (2)
\]

In this formula, k1 and k2 are the damping coefficients of two different rotation modes and \( \alpha \) are the angle between the cylinder shaft and the header plane of the combine. The relationship between \( \alpha \) and \( \theta \) can be obtained.

\[
sin \alpha = \frac{h \sin \theta}{\sqrt{h^2 + l_i^2 - 2hl_i \cos \theta}} \quad (3)
\]

The height of C and D from the ground can be obtained by further splitting the header structure of the combine.

\[
z_1 = -l \cos \theta + \frac{t}{2} \sin \beta \sin \theta + d_i \quad (4)
\]

\[
z_2 = -l \cos \beta - \frac{t}{2} \sin \beta \sin \theta + d_i \quad (5)
\]

In this formula, Z1 represents the height of C and Z2 represents the height of D.

To further optimize the above formula, the linear operation is carried out, and formula (3) is brought into formula (1) and (2), it is concluded that:

\[
(\Delta F_M + \Delta F_N)l_s \sin \alpha_s + (F_{M_s} + F_{N_s})P \Delta \theta - \frac{1}{2} m g l \sin \theta \Delta \theta - k_i \Delta \dot{\theta} = J_i \Delta \ddot{\theta} \quad (6)
\]

\[
(\Delta F_M - \Delta F_N) \sin \alpha_s \frac{t}{2} \cos \beta_s - k_s \dot{\beta} = J_s \Delta \ddot{\beta} \quad (7)
\]

\[
\Delta z_1 = l \sin \theta \Delta \theta + \frac{t}{2} (\cos \beta_s \sin \theta \Delta \beta + \sin \beta \cos \theta \Delta \theta) + d_i \quad (8)
\]
The state-space model of the combine header can be established from formula (6), (7), (8), (9), and then the optimal calculation can be realized. Table 1 shows the detailed state parameters of the combine header.

$$\Delta z_2 = l \sin \theta_2 \Delta \theta - \frac{t}{2} (\cos \beta_2 \sin \theta_2 \Delta \beta + \sin \beta_2 \cos \theta_2 \Delta \theta) + d_2$$  \quad (9)

Furthermore, state variables, input variables, and output variables are imported into the formula.

$$x = \begin{bmatrix} \Delta \theta & \Delta \dot{\theta} & \Delta \beta & \Delta \dot{\beta} \end{bmatrix}^T$$

$$y = \begin{bmatrix} \Delta z_1 & \Delta z_2 \end{bmatrix}^T$$

$$u = \begin{bmatrix} \Delta F_m & \Delta F_N \end{bmatrix}^T$$

Then the state space equation is obtained as follows.

$$\dot{x} = Ax + Bu$$

$$y = Cx + d$$

Among them, A, B, C, and D are.

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ -5.73 & 0.028 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0.870 \end{bmatrix}$$ \quad (12)

$$B = \begin{bmatrix} 0 & 0 \\ 0.00198 & 0.00196 \\ 0 & 0 \\ 0.02573 & 0.02538 \end{bmatrix}$$ \quad (13)

$$C = \begin{bmatrix} 1.733 & 0 & 0.316 & 0 \\ 1.733 & 0 & -0.316 & 0 \end{bmatrix}$$ \quad (14)

$$D = \begin{bmatrix} d_1 \\ d_2 \end{bmatrix}$$ \quad (15)

Let \( \ddot{x} = x + d' \), where \( d' \) satisfies \( Cd' = d \), we can get the state space as follows.
The parameters $A$, $B$, $C$ and $d\hat{\sigma}$ can be obtained from (12), (13), (14), (17), respectively.

$$d\hat{\sigma} = \begin{bmatrix} 0.29(d_1 + d_2) \\ -1.672(d_1 + d_2) \\ 1.572(d_1 - d_2) \\ 0 \end{bmatrix}$$

From this, the dynamic model of combine header ground profiling is obtained.

3. Design of ground profiling sensing mechanism

3.1 Design of sensing mechanism

As shown in Figure 2, when the profile wheel moves from point C to point D, the profile wheel will adjust according to the different height of the ground. Therefore, $h_1$ and $h_2$ are the distances between the rocker arm mounting point and the profiling wheel under different ground undulations. $\Delta h$ is the ground height difference after the profiling wheel moves from C to D. The angle between $a_1$ and $a_2$ rocker arms and ground C and D. In the process of profile wheel running, when the ground fluctuates, the angle between rocker arm and ground will change accordingly, the Flow Chart of Profiling ECU Based on Symmetric Algorithm is shown in Figure 3.

Figure 2. Movement Diagram of Profile Wheel on Header of Combine
3.2 Platform control test

the height of the uphill section is 14.7cm, and that of the downhill section is 16.5cm. At the interface of the two tracks, a path section is set up, which is uphill first and then downhill. After the test, the highest sampling rate of the sensor can reach 600kHz, and the signal is collected once every 20ms, a total of 437 times. Since the digital quantity corresponding to the displacement signal collected by the sensor is output by the profiling ECU. Therefore, the distance between the rocker arm mounting point and the profiling can be obtained from the following formula, i.e. the relative height $h$.

$$h = \frac{U}{4096} \cos \alpha$$

Among them, $U$ is the analog voltage signal generated by the rocker angle, $\alpha$ is the angle between the rocker arm and the vertical direction, and $X$ is the digital quantity corresponding to the analog voltage signal. Taking the horizontal ground as the benchmark, the distance between the rocker arm mounting point and the horizontal ground is taken as the height $h_1$, and the collected $h$ after the experiment is taken as $h_2$, which is brought into the formula $h = L \cos \alpha$. 

Figure 3. Flow Chart of Profiling ECU Based on Symmetric Algorithm
4. Conclusion
In this context, to improve the accuracy of combine header ground profiling control, the relevant ground sensing mechanism was studied and designed. The control mechanism of header ground profiling has a pilot sensing paradigm, which can sense the real terrain data before the operation, thus improving the accuracy of header ground profiling. At the same time, placing the profiling mechanism in the front of the shovel can effectively improve the profiling accuracy and reserve enough response time for the hydraulic system.

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