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Design and Simulation of the Operating Speed Regulation Algorithm of Plot Cabbage Seed Combine Harvester

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Abstract

Aiming at the problems of the single control scheme, the few aspects of monitoring and diagnosis, and the large delay time of the plot combine harvester, this paper designs the forward speed control algorithm of the plot Chinese cabbage seed harvester. This paper studies the theory of association rules, has used SQL Server to build a database including the job parameters of the main monitoring objects, and has mined the association rules between the job parameters and the feed amount through Analysis Service. Combining the knowledge of association rules and ordinary fuzzy PID algorithm, the article has built a model and performed simulation verification. The results show that the algorithm can adjust the forward speed reasonably and quickly when the feed volume increases.

Key words: Plot Harvest, Association Rules, Fuzzy Control, Intelligent Control

Preface

China is a large population country with a large demand for food. With the rapid development of society, the urban population continues to rise, and the domestic cultivated land continues to decrease. In agricultural life, the most critical means of production that can't be replaced is crop seeds. With the help of community experiments, breeding experts select good seeds with high yield and obtain sufficient food on the shrinking cultivated land. This measure is the main way to ensure the stability and safety of economy and people's livelihood. With the wide application of seed harvester in community by breeding units and scientific research institutions at all levels, the function of seed combine harvester in community becomes more powerful and complex, and the working efficiency is greatly improved. The field working environment is bad, and under the working environment of joint harvester, unpredictable faults often occur. Because most harvester operators are not trained, only with personal experience to judge the working conditions. This will not only lead to the increase of harvester loss, the obvious increase in the incidence of failure, work efficiency, but also increase the loss of the test. Therefore, it is necessary to study intelligent monitoring and control system to improve the efficiency of joint harvester. In order to promote the harvester in the field work process, stable and produce higher efficiency, reduce the driver processing workload, this paper designs a speed control algorithm based on association rules for the joint harvester of Chinese cabbage seeds in residential area.

1. Control programme design

The main reason for the blockage failure of the combined harvester is that the increase of feed volume exceeds the normal working range. During the inter-field operation of the combined harvester, the main working parts affecting the change of feeding quantity are threshing drum, plucking wheel, feeding churning dragon and so on. Therefore, the system needs to control the variation range of feed quantity within the normal working range to ensure the low failure, high quality and high efficiency of the Chinese cabbage seed harvester in the residential area.

A fuzzy PID control strategy combining association rules is proposed. The control algorithm mainly takes the deviation and the change rate of the deviation of the rotational speed parameters such as threshing drum, plucking wheel and feeding churning dragon as the system control reference. In this way, the feeding amount can be kept within the normal range and the harvester can be guaranteed to harvest in the field in accordance with the normal operation process. By changing the voltage value to control the servo valve flow and then change the speed of the hydraulic motor, so as to achieve the effect of changing the speed.

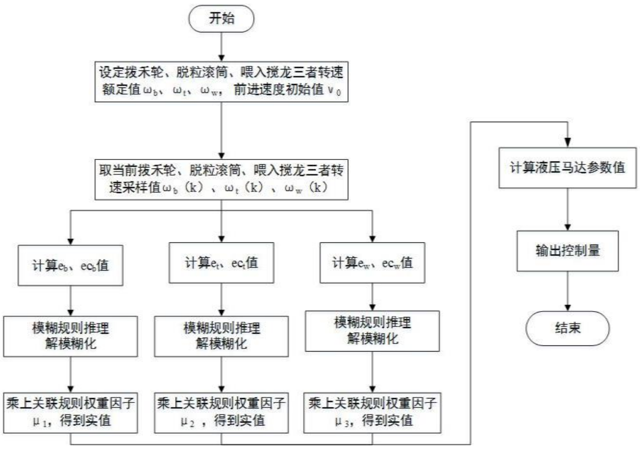

Figure 1. Block diagram of fuzzy PID working speed control algorithm based on association rules

2. Association rule mining

2.1 Theoretical Basis of Relevance Rules

Mining association rules is the discovery of previously unknown or hidden relationships between data in a database. These relationships are mainly related rules and theories that have high value for control decisions. Therefore, the mining of association rules is to distinguish frequent item sets in the data, and then to construct the rule process of expressing association relations. Apriori is the mainstream algorithm in the association rule algorithm family, and its main parameters are confidence and item set(Rao et al., 2012), etc.

Suppose I={ i set of items i_1, i_2,.....,i_m } is a collection of m different items. Transaction T={ t_1t_2, ...,t_m } is a collection of items in an item set I, so T⊆ I. If X is a subset of I data and X is also a subset of T, then T contains X. The transaction T is the unique identity of the TID recognizer. Transaction database DB is a collection of a certain number of different transactions T.

Support(X) of item X, refers to the degree of importance that X has. X.Count is the number of supported transactions for X, which refers to the number of transactions in the transaction database that support X. Assuming that |DB| is the number of all records in the database, the degree of support X available is shown in formula (1).

$$\text{Support}(X) = P(X) \approx \frac{X \cdot \text{count}}{|DB|} \qquad (1)$$

If the item set X⊆I, Y⊆I, at the same time X∩Y=Ø, then R: X⇒Y has the implication, and belongs to the association rule. It indicates the transaction T that includes X, large probability including Y. So X is a rule antecedent or a set of antecedents, and Y is a rule antecedent or a set of after items. When the proportion of transactions contained in the DB is reached, the degree of support, namely Support(R), will be s%; if the transaction containing the X is a transaction with Y, the confidence is c%. The formula of support and confidence of rules X⇒Y is shown in formula (2) and formula (3).

$$\text{Support}(R) = \text{Support}(X \cup Y) = P(X \cup Y) \approx \frac{XY.\text{Count}}{|DB|} \quad (2)$$

$$\text{Confidence }(R) = P(Y \mid X) = \frac{\text{Support}(X \cup Y)}{\text{Support}(X)} \approx \frac{XY.\text{Count}}{X.\text{Count}} \quad (3)$$

S_{min} represents the minimum support threshold is the minimum support required to seek the task. The X belongs to the frequent item set if the support of the X Support (X) of X ≥ S_{min}. $Conf_{min}$ represents the minimum confidence threshold and the minimum credibility when the rules meet the task requirements.

The importance can also be called the gain. The importance of an item set is the ratio of confidence to support of the latter item set, that is

$$\text{Importance}(X,Y) = \frac{\text{Confidence}(X \cup Y)}{\text{Support}(Y)} \quad (4)$$

The importance of the rules is calculated by the following formula:

$$\text{Importance}(X \Rightarrow Y) = \log \frac{P(X \mid Y)}{P(X \mid \bar{Y})} \quad (5)$$

For the Importance of rules, if Importance=0, Y is irrelevant to X; If Importance>0, then there is a positive correlation between the two, after the appearance of X, the probability of the appearance of Y is relatively high; If Importance<0, then there is a negative correlation between the two, after the appearance of X, the occurrence of Y is less likely. In the provided transaction database D, we seek the minimum confidence degree $Conf_{min}$ and minimum support degree S_{min} that meet the user conditions, and there are association rules that are more important than the minimum, namely strong association rules.

Association rules algorithm mainly includes two parts: algorithm generation and frequent item set generation. The first part is the minimum importance, frequent item set and minimum confidence as input parameters, and the output is the set of association rules. The second part is the minimum support S_{min} and database DB as input, and the output is all frequent item sets L in the database.

2.2 Establishment of a harvester database

Table 1 shows the test conditions of harvesting operation under manual operation. The data are recorded by the harvester's working parameter monitoring system, so as to obtain relevant information about the rotation speed of the cleaning fan, the tilting wheel and the threshing drum. According to the test, the rated speed of threshing drum is 950 r/min, the rated speed of feeding churn is 255 r/min, the rated speed of threshing wheel is 55 r/min, the rated speed of cleaning fan is 1800 r/min.

The main influencing factors of feeding amount include crop variety, crop density, stubble height, width of cutting, ratio of grain to grass, moisture content and operating speed. The feeding quantity is random and there is an approximate mathematical model between it and other data(Wang et al.,2012).As shown in formula 6.

$$q = \rho H v (1+\delta) / \delta \quad (6)$$

ρ represents crop yield per unit area, kg/m^2, *v* represents the speed of advance, the m/s ;*H* represents the width of the cut, the m ;*q* represents the amount of feed, and the kg/s ;*δ* represents the ratio of grain to grass.

Table 1 Environmental conditions of Chinese cabbage seed harvest test

Serial number	Project	Unit	Observation results
1	Crop types	/	F1 No .3
2	Plant height range	cm	88-120
3	Plant lodging	/	Serious
4	1000 Weight	G	4.15
5	Output per unit area	$Kg.m^{-2}$	0.18
6	Cutting width	H	1.2
7	Wheatgrass ratio	**/**	0.15

The operation parameter sample database established consists of data such as speed of feeding wheel, speed of feeding auger, speed of threshing drum, forward speed and feeding amount, which mainly records data under no-load operation and full load harvesting operation state. Table 2 shows some sample data in the job parameter data table.

Table 2 Operation parameter data of plot seed harvester

Record number	Moving forward Speed m/s	threshing drum Speed r/min	Pulling of grass Speed r/min	Feed the dragon Speed r/min	Feed quantity kg/s
1	0.75	945.41	49.87	236.93	1.27
2	1.04	933.26	49.23	233.89	1.77
3	1.05	930.16	49.07	233.11	1.78
4	1.19	912.31	48.13	228.63	1.83
5	1.32	892.99	47.11	223.79	2.04
6	1.16	915.45	48.29	229.42	1.68
7	1.20	907.30	47.86	227.38	1.74
8	1.15	916.88	48.37	229.78	1.67
9	1.09	927.40	48.92	232.42	1.68
10	1.04	930.08	49.06	233.09	1.71
11	1.02	931.22	49.12	233.38	1.73
12	0.97	935.11	49.33	234.35	1.65
13	1.00	932.10	49.17	233.59	1.70
14	1.01	929.08	49.01	232.84	1.71
15	1.04	931.29	49.13	233.39	1.76
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16	1.06	935.21	49.33	234.38	1.79

2.3 Rule mining of job information

When some parameters that have an effect on harvester performance, such as air volume of cleaning fan and environmental conditions of Chinese cabbage seed harvest test, are in normal working state, association rules mining of harvester working database is carried out with the help of Analysis Service component built in SQL Server(Liu et al., 2012). Since the feed quantity is an important evaluation factor for the performance of harvest, this paper designed the operation parameter data table to mine the structure, set the feed quantity as the prediction quantity, set the forward speed, drum speed, etc., as the input quantity, set the record number as the key, and set the minimum support number of association rule algorithm as 150.

Figure 2. Association rule mining diagram of job data

The mining model in the Analysis Service selects the job data table and the mining viewer selects the Microsoft association rule viewer. The system software will interval the value of the parameters, providing a minimum confidence $Conf_{min}$ of 0.50 and a minimum $Importance_{min}$ of 0.60 to get a strong association rule.

2.4 Extraction and Analysis of Strong Association Rules

The expected loss rate is as low as possible while the feeding amount should be as large as possible within the range of rating. Find the association rules of the optimal feeding amount from the association rules of the job information parameters, and ensure the same foreparts of the rules. After comprehensive consideration, extract three strong association rules of the feeding amount, as shown in Table 3.

Association rule data mining is mainly to mine the existing sample data in the established database. The purpose of mining is to find out the influence of each factor on the importance and confidence of the target, and it is a rule of great relevance in the strong association table. The rule front part can be considered as the input parameter of the association rule mining algorithm, and the rule back part can be considered as the output parameter. The mining of association rules can find frequent item sets higher than minimum confidence and minimum importance from things that seem to have no specific and accurate formula relationship, if the object appears more times, the greater the impact. The discovery of strong correlation will improve the overall stability of the system.

When the installation parameters of all the components of the threshing drum, the air volume of the cleaning fan and the crop type properties of the harvester are derived from the reasonable working state category, the strong correlation rules in Table 3 are as follows: the first rule indicates that the feeding amount is 1.45-1.91kg/s when the rotating speed of the pulley is above 52.64 r/min; the second rule indicates that the feeding amount is 1.45-1.1kg/s. When the feeding r/min is above 240.11 r/min; and The second rule indicates that when the rotational speed of the auger is above 240.11r/min, the feeding amount is within the range of 1.45-1.91kg/s, which has a good credibility and a relatively high possibility. The third rule indicates that when the threshing drum speed is above 870.18 r/min, the feeding amount is about 1.45-1.91 kg/s range, and the threshing drum speed is more important than the effect of the feeding speed on the feeding amount.

According to the importance of knowledge and confidence, the weight factors of association rules are confirmed between each working parameter and feed quantity by normalization. Due to incomplete data acquisition, it is necessary to measure the degree of correlation between the rotary speed, the feeding speed of the auger and the feeding amount. Therefore, the weight interval of threshing drum speed ω_1, threshing wheel speed, feeding auger speed is set respectively, the weight interval of threshing drum speed is set as [0.4 0.6], the weight interval of cereal wheel speed ω_2 is set as [0 0.2], the weight interval of feeding auger speed ω_3 is set as [0.3 0.5].

Tab .3 Work parameter strong association rule table

Serial number	Pre-rule	Rule back	(Importance, confidence)
1	Bucket wheels (≥52.64)	Feed (1.45-1.91)	（1.669，1.000）
2	Feeding churn (⩾240.11)	Feed (1.45-1.91)	（1.859，1.000）
3	threshing drum (≥870.18)	Feed (1.45-1.91)	（1.969，1.000）

3. Establishment of Joint Harvesting Machine Model of Chinese Cabbage Seed in Cell Area

This system control algorithm with threshing cylinder rotation speed, wheel speed, feed is designed to stir the dragon variation of the rotational speed difference and rate control algorithm for system input basis, through the processing of fuzzy PID operation speed controller, according to the weighted association rules in data processing, get homework speed adjustment, on the walking system to adjust and control of the servo valve and hydraulic motor, thus the operation speed of adjustment to the expected value, ensure feeding quantity in a reasonable range. The above process mainly involves the modeling of threshing drum and walking system. The specific content is as follows:

(1) Modeling of threshing drum

The dynamics of crops in threshing space is complicated, and the relative slip and humidity of crops such as grain stem have significant effects on threshing power consumption and quality. In the process of field operation, the seed harvester in residential area requires that on the basis of the failure of the harvester itself without blockage caused by the field working environment, the higher the efficiency of the harvest operation, the lower the loss rate is, the higher the quality of the harvest operation is. In order to reduce the complicated mechanical problems, and devote to the dynamic characteristics of the space feeding, the following assumptions can be made(Zhang et al.,1999)：

①Uniform and continuous feeding of crops during threshing, ignoring the effect of crop humidity;

②Grain is fitted with cover plate or gravure plate, continuous flow, there is no relative sliding between crop layers;

③The grain released during threshing is separated by gravure plate at the same circumference velocity as the drum.

Literature (Zhang et al.,1999) power consumption model based on drum speed, crop density, walking speed and so on, provided in the literature, reflects the power consumption of the drum, the correlation with the motion parameters and the structure of the thresher, as shown in formula (7).

$$\frac{d\omega}{dt}=\frac{N}{J\omega}-\frac{\left(A+B\omega^2\right)}{J}-\frac{qr^3\omega}{2J\left(1-f\right)}\cdot\frac{\delta+\lambda}{1+\delta} \qquad (7)$$

In Formula (7), N is the input power of the drum, kw; ω is drum angular velocity, r/min; J is the moment of inertia, kg•m^2; q is the feeding quantity at the entrance of the drum, kg/s; A and B are constants; R is the drum radius, m; δ is the seed-grass ratio; λ is the crop export speed ratio; f Represents the rubbing coefficient of the roller.

(2) Modeling of walking systems

The control order of adjusting the forward speed of the Chinese cabbage seed combined harvester in the residential area is mainly to change the flow rate of the hydraulic motor by giving the servo valve voltage value, and then to drive the gear conveyor belt to adjust the forward speed. The servo valve is modeled to establish the relationship between input voltage and output flow, which can be obtained by finding its transfer function. According to the literature(Xing et al.,2020), if the bandwidth of the servo valve is close to the natural frequency of the hydraulic pressure, the servo valve can be regarded as a second order oscillation link:

$$K_S G_S(s) = \frac{Q_0}{U} = \frac{K_S}{\frac{s^2}{\omega_S^2} + \frac{2\xi_S}{\omega_S} s + 1} \tag{8}$$

In formula (8) : K_S represents the flow gain of the servo valve, $m^3/(s\cdot V)$; U represents the servo valve voltage, V; ω_S denotes the servo valve's natural frequency, Hz; G_S represents the transfer function when the servo valve is at K_S=1; ξ_S represents the damping ratio of the servo valve.

Therefore, the valve-controlled hydraulic motor modeling, with the aid of the acquired transfer function, the relationship between the motor speed and the input flow is constructed. The transfer function of speed and no-load flow(Xing et al.,2020)is:

$$\frac{\theta_m}{Q_0} = \frac{1/D_m}{s(\frac{s^2}{\omega_h^2} + \frac{2\xi_h}{\omega_h} s + 1)} \tag{9}$$

(3) Fuzzy PID control model of operation speed based on association rules

The main components of the harvester are driven by the engine with the help of transmission mechanism and intermediate shaft to achieve power transmission. Therefore, the speed of the threshing drum is approximately proportional to the speed of the feeding auger at the cutting table(Zheng et al.,2011). And based on the knowledge of the correlation between feed rate and forward speed combined with the operational speed control model. A system simulation model based on association rules is established by Simulink components. The rated value of the main monitoring parts in the working process of the harvester is set according to the data obtained by the test. The threshing drum speed is 950 r/min, the threshing wheel speed is 55 r/min, and the feeding speed is 255 r/min. The main function of Scope of oscilloscope is to record the whole process of the type with varying forward speed. Therefore, Scope1 monitors and records the rotating speed of the threshing drum in the whole process.

When in automatic control mode, the system will monitor in real time if the speed of the parts such as the dragon is fed. A fuzzy PID control model based on association rules adjusts the forward speed by means of a number of fuzzy controllers to ensure that the harvester has a suitable feeding capacity from beginning to end, so as not to reduce the working performance of the harvester due to excessive changes in the feeding capacity.

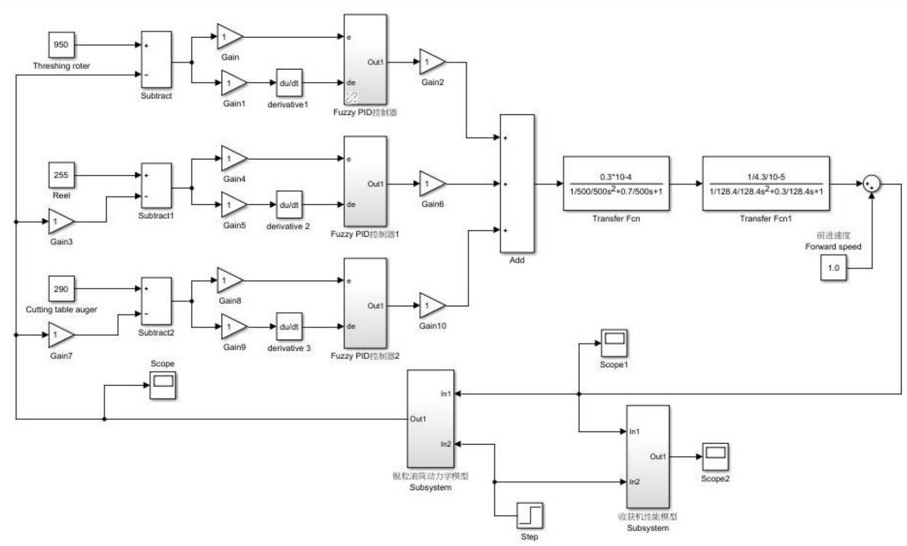
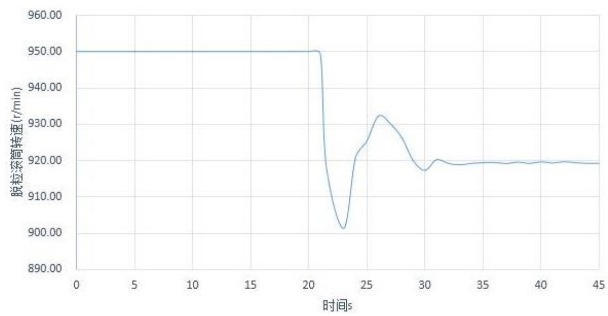


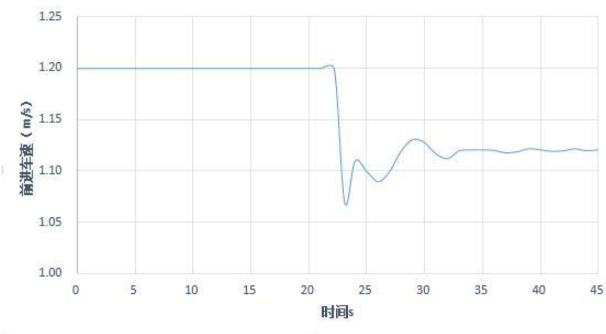
Figure 3. A speed control model for harvester with knowledge of association rules

4. Simulation of Operation Speed Control Algorithm

According to the designed model, the operation speed is controlled in the simulation environment. The simulation conditions are as follows: the simulation control time is 45 seconds; the rated speed of threshing drum is 950r/min; the forward speed is 1.2m/s; At 20 seconds per unit area, a step change occurred with the increase of from 0.18kg/m2 to 0.21 kg/m2, resulting in an increase in crop feed of approximately 15%.



(a) Rotation curve of drum



(b) Forward velocity curve

Figure 4. Simulation curve of association rule controlling model speed

Figure 4 (a), (b) threshing drum speed and forward speed simulation curve, under the influence of fuzzy controller, In 20 seconds, the surge capacity per unit area, but crops by feeding beat the dragon to the conveying groove, and then passed to the process of threshing cylinder, there is delay time of 1.5 seconds, so in 21.5 seconds, the roller speed began to change, after 1.5 seconds, reduce speed to 901 r/min, and then after 10 seconds, roller speed regulation by the controller swings around 919 r/min; Through the processing of hydraulic speed control equipment, The forward speed begins to decrease after a delay of 0.8 seconds.

After about 1 second, the speed decreases to 1.07 m/s and then increases gradually. After about 10 seconds, the speed fluctuates up and down at 1.12m/s through constant adjustment by the controller. The simulation results show that the control system can reasonably adjust the forward speed and drum speed when the feed volume increases by about 15%. Compared with the rated speed of the threshing drum, the maximum range of change is 5.16%, and the relative range of steady state is about 3.26%, which can effectively prevent the drum from blocking and overload. Compared with the rated value, the maximum range of the forward speed is 10.8%, and the relative range of the steady state is about 6.67%. System adjustment takes about 11s.

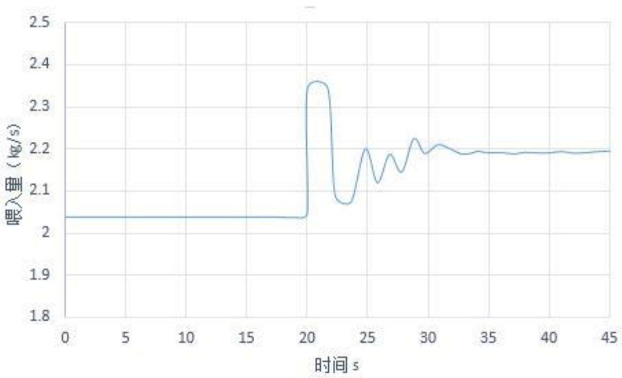


Figure 5. Simulation curve of feed rate of association rule model

According to the simulation curve of feed quantity in figure 5, 0~20 seconds, the corresponding curve is horizontal, Feed is about 2.04 kg/s. In the 20th second, Because of the step change in output per unit area, about 15% higher, leading to a step change in feed volume, Increase to about 2.34 kg/s. Through hydraulic transmission, there's a delay of about 0.8 seconds, the crop is fed into the churning dragon to the delivery tank, And into the threshing drum, About 1.5 seconds of delay, so the crop in the drum, Change at about 22.3 seconds. After the forward speed is adjusted by the controller, it is reduced to the minimum value of 1.76kg /s after about 1 second, and then it is stabilized around 2.19kg /s through constant control by the controller.

According to the comparison diagram of the current threshing drum speed and speed simulation curve, it can be seen that if the feeding capacity of the harvester increases, the threshing drum and the forward speed can be effectively controlled so that the rotational speed change of the drum is always kept in a reasonable range. Therefore, the system can effectively avoid load overload or drum blockage, and also meet the actual needs of joint harvester harvesting operation, indicating that the joint harvester control model is reasonable and feasible.

5. Conclusions

According to the design of the control scheme, design the fuzzy PID operation speed control algorithm based on association rules, and established the plot Chinese cabbage seeds combine control system model, the application of the test data on the algorithm simulation test, the test results show that when the feed rate increased by 15%, the variations in the steady speed of drum about 3.26% of its rated speed, the time needed for system adjustment process about 11 s. Therefore, the fuzzy PID operation speed control algorithm based on association rules has fast response speed, good stability, strong robustness, and meets the expected effect.

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