In-field experiment of electro-hydraulic tillage depth draft-position mixed control on tractor

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Abstract. The soil condition and condition of the plow affect the tillage resistance and the maximum traction of tractor. In order to improve the adaptability of tractor tillage depth control, a multi-parameter control strategy is proposed that included tillage depth target, draft force aim and draft –position mixed ratio. In the strategy, the resistance coefficient was used to adjust the draft force target. Then, based on a JINMA1204 tractor, the electro-hydraulic hitch prototype is constructed that could set control parameters. The fuzzy controller of draft –position mixed control is designed. After that, in-field experiments of position control was carried on, and the result of experiment shows the error of tillage depth was less than ±20mm. The experiment of draft-position control shown that the draft force and the tillage depth could be adjust by multi-parameter such as tillage depth, resistance coefficient and draft- position mixed coefficient. So that, the multi-parameter control strategy could improve the adaptability of tillage depth control in various soils and plow condition.

1. Introduction
The electro-hydraulic hitch system of tractor can realize single parameter or multi-parameter control in the tillage operation, such as position control, draft control and draft-position mixed control in tillage operation [1-3], in addition, slippage ratio control [4] and drive torque [5] control can also be carried out. Compared with the traditional mechanical depth control, the electric hydraulic control system has the higher precision in depth control, better effect in slip control and energy saving [6]. Therefore, the control strategy of electro-hydraulic of tractor has become the focus of research. Some scholars have studied the control strategy of electro-hydraulic hitch system in plough work by simulation and bench test, and obtained better results [7-8]. Considering the difference between the laboratory test conditions and the field tillage conditions, the soil resistance of the test bench is simulated by the mechanical loading simulation according to the given soil model [9]. The soil composition, humidity and speed of tractor will affect the soil specific resistance in tillage [10-11], and the adjustment of plow will also affect the draft load of the tractor. These will cause the actual tillage depth deviating from deep tillage set target because of soil physical conditions and plow implement condition in draft-position mixed control. Therefore, this paper proposes to add a resistance factor in the draft-position mix control, by adjusting this resistance factor, the depth of tillage will float near the setting depth value and improve the adaptability to soil conditions and plow working conditions.
2. Research on draft-position mixed control strategy

2.1. Position control strategy and draft control strategy

The target of position control is the depth parameter, which is the basis of draft-position mixed control, and the deviation \( h \) of the depth target is written as:

\[
h = (H_s - H_m)
\]

Where \( H_s \) is to set tilling depth values; \( H_m \) is to detect tillage depth values.

The draft control target can be obtained by setting the tillage depth and given soil specific resistance, and are written as the following:

\[
F_o = K \cdot H_s \cdot b
\]

Where \( K \) is soil specific resistance, \( N/cm^2 \); \( b \) is tillage width of plough, cm.

From the formula (2), The resistance target depends on the setting depth value when the soil specific resistance \( K \) is given. In addition to tillage depth parameters, soil conditions and plow conditions also affect tillage resistance. Therefore, in the resistance control, it is necessary to set up the resistance target separately. A resistance factor is proposed here that can be set according to the soil condition and the plow condition, and the resistance control target can be set separately by the resistance coefficient. The target of draft control is written as follow:

\[
F_o = K \cdot H_s \cdot b \cdot \beta
\]

Where \( \beta \) is the resistance factor. According to the investigation of soil specific resistance in East China [12], the mean value of \( K \) is 6 \( N/cm^2 \), and the range of \( \beta \) is 1~2. It can be seen from the formula (3) that the target of draft control can be adjusted by the resistance coefficient when the depth target is set. The deviation of tillage depth in the draft control can be written as:

\[
h = \left( \frac{F_o - F_m}{K \cdot b \cdot \beta} \right)
\]

Where \( F_m \) is a measure value of tillage resistance.

2.2. Draft-position mixed control strategy

The draft-position mixed control combines the advantages of position control and draft control, that can adjust the dual objectives including the depth of tillage and the of tillage resistance. Here, the participation ratio of the position target and the resistance target is adjusted by the mix coefficient \( \omega \). The deviation of tillage depth in the draft-position control can be written as:

\[
h = \left( \frac{F_o - F_m}{K \cdot b \cdot \beta} \right) \cdot \omega + (H_s - H_m)(1 - \omega)
\]

From the formula (5): when \( \omega = 0 \), the control mode is position control; \( \omega = 1 \), the control mode is draft control; \( 0 < \omega < 1 \), the control mode is draft-position is mixed control.

Control method of the electro-hydraulic hitch system can be shown by control schematic as Fig. 1 the setting parameter include depth object value \( H_s \), mix coefficient \( \omega \), resistance factor \( \beta \). The draft signal is measured by force sensor in the electro-hydraulic hitch system; The module of data acquisition and calculation collects the above signal, and calculate the depth deviation \( h \) and deviation change rate \( dh \); The controller calculates the control value \( u \) of electro-hydraulic proportional valve that control the tillage depth of plow to achieve draft-position control strategy of tillage work.
3. The electro-hydraulic hitch system prototype on the tractor
The electro-hydraulic hitch system prototype was built in the JINMA1204 wheeled tractor the hydraulic system parts mainly include hydraulic pumps, electro-hydraulic proportional valves (Sauer Danfoss), and single acting cylinders. The tillage depth value is measured by the real-time angle signal of lift-axis shown as Fig.2, an angle sensor (WDH22, FS 0.2%) is installed between the lift-axis and the frame of tractor to measure the angle displacement of the lift-axis, and the tillage depth parameters of the mounted plow can be calculated. The shaft type force sensors is used to replace the shaft that connects the traction frame and the hitch device, and the force signal of the hinge points is obtained, and the draft force of the tractor can be calculated by the force signal of the hinge points. A control box is mounted on the right side of the seat, and the control box includes a setting panel, a display and a controller. the set panel can be used to set the control parameters, such as depth object value $H_s$, mix coefficient $\omega$, resistance factor $\beta$. According to the sensor signal and the setting parameter signal, a control program in the controller to control the electro-hydraulic proportional valve, which is used to adjust the tillage depth of the plow. The controller has an CAN interface, which can be used to communicate and store signal data with the notebook computer.

4. The design of fuzzy controller
Tractor implement system is a nonlinear system, the different field operation requires the different tools, accurate mathematical model of tractor hydraulic hitch and implement cannot be obtained. However, the fuzzy control does not require a mathematical model of the controlled object, therefore, the draft-position control of tillage depth can adopt fuzzy control algorithm.

4.1. Input and output variables and membership degrees
The input parameter is the position deviation $h$ and the deviation change rate $dh$, and the output parameter $u$ is opening of the electro-hydraulic valve spool. The maximum tillage depth of the plow is 350mm, so the range of $h$ is [-350, 350]. The penetrating ability of plow relies on its gravity and its penetrating angle because lifting cylinder is single-action cylinder, so the valve need larger opening and less fuzzy subset when the downward regulation is performed, which is conducive to the plow down as soon as possible. The valve need small opening and fuzzier subset when the lifting regulation of the plow is carried on, which is beneficial to the lift accuracy of the plow. To sum up, the linguistic
variables of position deviation $h$ are designed for six fuzzy subsets, namely, negative big (NB), negative middle (NM), negative small (NS), zero (ZO), positive small (PS), and positive big (PB). Based on the previous experiments, the range of the deviation change rate $dh$ is $[-150, 150]$, the $dh$ was designed for six fuzzy subsets, namely negative big (NB), negative middle (NM), negative small (NS), zero (ZO), positive small (PS), positive big (PB). The universe of $h$ and $dh$ are $[-5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5]$, so the quantization scale factor of $h$ is $350/5$, and the quantization scaling factor of $dh$ is $150/5$. The membership functions of $h$ and $dh$ are shown in Fig. 3.

The electro-hydraulic valve is controlled by digital, the valve opening control $u$ is between $-255$ to $255$. The valve opening control $u$ is divided into six fuzzy subsets: negative big (NB), negative middle (NM), negative small (NS), zero (ZO), positive small (PS), and positive large (PB). The universe of $u$ is $[-6, -4, -3, -2, -1, 0, 1, 2, 3, 4, 6]$, and its quantization factor is $255/6$. The membership function of $u$ is shown in Fig. 4.

**4.2. Fuzzy control rule**

A larger opening of the valve opening is required when the deviation of tillage depth $h$ is large, which make the plow to quickly return to the depth target position. Similarly, a smaller valve opening is required when the deviation of tillage depth $h$ is small. As the decline of farm tools mainly depends on their gravity and the angle of descent, therefore, when the $h$ is positive deviation, the opening of the valve opening is larger, so that the farm implements can fall rapidly. The designed fuzzy control rules are shown in Table 1.

**Table 1. Fuzzy control rules**

| $u(i)$ | $h$ | $NB$ | $NM$ | $NS$ | $ZO$ | $PS$ | $PB$
|-------|-----|-----|-----|-----|-----|-----|-----
| $NB$  | $PB$ | $PB$ | $PB$ | $PS$ | $PS$ | $PS$ | $PS$
| $NM$  | $PB$ | $PS$ | $PS$ | $PS$ | $PS$ | $PS$ | $ZO$
| $NS$  | $PS$ | $PS$ | $PS$ | $PS$ | $ZO$ | $ZO$ | $ZO$
| $ZO$  | $PS$ | $PS$ | $PS$ | $ZO$ | $ZO$ | $ZO$ | $NM$
| $PS$  | $ZO$ | $ZO$ | $NS$ | $NS$ | $NS$ | $NS$ | $NM$
| $PB$  | $NS$ | $NS$ | $NM$ | $NM$ | $NB$ | $NB$ | $NB$

**5. Field experiments**

Field tillage experiments can examine the accuracy of tillage depth control and the effect of draft-position mixed control under different control parameters.

**5.1. Experiment scheme**

The draft-position mixed control is generally used in large tillage depth operation; therefore, the tillage depth target is set 300mm. The position control experiment ($\omega=0$) and draft-position mixed control
experiment has carried in different mix coefficient $\omega$ and resistance factor $\beta$. When the resistance coefficient $\beta$ is set to 1, the draft-position control mixed experiments of $\omega = 0.1$ and $\omega = 0.5$ are performed respectively. The draft-position control mixed experiment of the $\beta = 1.5$ is performed while the mix coefficient $\omega$ is 0.5. The notebook computer carries on the data communication with controller by the CAN to the USB module, and carry on the data collection by the Plus+ service tool software (Sauer Danfoss) in the experiments. In the test, the work speed of the tractor is 5~7 kilometres in tillage gear. In the test, the operation speed of the tractor is 5~7 km/h. The test site is the experimental field of Mahindra Yueda(Yancheng) Tractor Co., Ltd in China (longitude: 120.13; latitude: 33.38).

5.2. The result analysis

The curves of tillage resistance and depth are plotted by processing the experimental data. As shown in Fig.5, the horizontal ordinate represents time, and the main ordinate represents the tillage depth. The tillage depth is less than 0, which indicates the plough has a depth of penetration under the soil; The tillage depth is greater than 0, which indicates the plough has a distance above the soil. The secondary ordinate indicates resistance. The resistance is greater than 0, that means the lower link is pulled; The resistance is less than 0, that indicate the lower link is under pressure. (when the plow is hanged, the lower link is pressed).

![Figure 5](image-url)

**Figure 5.** In-field experiments results of tillage control

Fig.5 (a) is the position control ($\omega=0$) curve diagram that set value of depth is 300mm. The a part of the plough is from the surface of the soil to the setting of tilling depth, and the penetration time is 4.8 seconds. The tillage depth is kept near 300mm, and the fluctuation range is less than $\pm 20$mm. Fig. 5 (b), Fig.5 (c) and Fig.5 (d) are curves of the draft-position mixed control that the depth target is 300mm. In order to analyze the experimental results of different mixed coefficient $\omega$ and resistance factor $\beta$, the mean and variance of tillage depth, mean of tillage resistance were calculated and shown in Tab. 2 in every experiment.
Table 2. Analysis of experiments data

| $\omega$ value | Depth mean value (mm) | Depth mean deviation(mm) | Resistance mean value (kN) |
|----------------|------------------------|--------------------------|----------------------------|
| $\omega=0$     | 302                    | 6.6                      | 34.4                       |
| $\omega=0.1, \beta=1$ | 287                    | 8.9                      | 32.7                       |
| $\omega=0.5, \beta=1$ | 251                    | 13.1                     | 29.2                       |
| $\omega=0.5, \beta=1.5$ | 276                    | 11.2                     | 31.4                       |

From Tab. 2, the deviation of the tillage depth is less than the setting target of tillage depth. In the draft-position mixed control, when resistance coefficient is same ($\beta=1$), the mix coefficient $\omega$ is greater, the deviation value of tillage depth is greater. This shows that, the control target of tillage depth decreases as the $\omega$ increases. In the same mix coefficient ($\omega=0.5$) test, the resistance coefficient $\beta$ was increased from 1 to 1.5, and the tillage depth was increased from 251mm to 276mm, which indicates that the tillage depth can be adjusted to the set target by adjusting the resistance coefficient $\beta$. From mean of tillage resistance in Tab. 2, adjusting mix coefficient $\omega$ and resistance coefficient can adjust control target of tillage resistance; In this field experiment, the increase of mix coefficient $\omega$ make tillage resistance decrease, the increase of resistance coefficient $\beta$ make tillage resistance increase, thus the regulation of the target of draft force is realized in draft-position control.

6. Conclusion
The control method of depth and tractor draft is analyzed, and a method of draft-position mixed control including three parameters (mix coefficient $\omega$, resistance coefficient $\beta$, tillage depth $H_s$) is proposed. The electro-hydraulic hitch system is built on the JINMA1204 wheeled tractor, and the fuzzy controller is designed. In the experimental field, the position control experiment with its depth target 300mm was carried out. The plow reaches the depth target in 4.8s, and the error of tilling depth is less than ±20mm. These results indicated of the prototype and fuzzy controller designed is correct.

The draft-position control test in different mixed coefficient and the resistance coefficient was carried out, and test results show that the depth dispersion increase with increasing of the mixed coefficient, of control target of draft force can be adjusted by resistance coefficient, which increase the adaptability of tillage depth control on the different soil conditions and conditions of the plow.

Acknowledgments
This work was supported by foundation of National Key R&D Program of China (863 program NO: 2016YFD0700402) and foundation of Jiangsu University (NO: 11JDG044).

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