agriculture

MDPI

Review

Development Status and Research Progress of a Tractor Electro-Hydraulic Hitch System

Xiaoxu Sun [1], Zhixiong Lu [1,*], Yue Song [1], Zhun Cheng [2], Chunxia Jiang [3], Jin Qian [1] and Yang Lu [1]

[1] College of Engineering, Nanjing Agricultural University, Nanjing 210031, China
[2] Department of Vehicle Engineering, Nanjing Forestry University, Nanjing 210037, China
[3] College of Mechanical Engineering, Anhui Science and Technology University, Chuzhou 233100, China
* Correspondence: luzx@njau.edu.cn; Tel.: +86-13951715780

Abstract: A tractor electro-hydraulic hitch system is considered one of the most important systems that play a strategic role in the power transmission and operation depth control of a tractor's field operation. Its performance directly affects the operation quality of the whole work unit of the tractor. Furthermore, a tractor electro-hydraulic hitch system has gained the interest of many in the agricultural machinery sector because of its stable performance, high production efficiency, good operation quality and its low energy consumption. To fully benefit from the potential of the tractor electro-hydraulic hitch system, it is significant to understand and address the problems and challenges associated with it. This study, therefore, aims to contribute to the development of the tractor electro-hydraulic hitch system by investigating the research methods, technical characteristics and emerging trends in three key aspects that include the tillage depth adjustment method, the tillage depth control algorithm and the core components of the electro-hydraulic hitch system. The characteristics and applicable conditions of the different tillage depth adjustment methods of the electro-hydraulic hitch system were summarized. The realization methods and the control characteristics of the different algorithms were elaborated and discussed for both the PID control algorithm and the intelligent control algorithm. The working characteristics of the core components of the electro-hydraulic hitch system were analyzed based on the hydraulic control valves and sensing elements. The results have shown that the multi-parameter tillage depth adjustment method met the operation quality standard while taking the engine load stability and traction efficiency into account, and it has a greater research significance and value. The working quality can be improved effectively by introducing the intelligent algorithm. In addition, the study of smart valves with built-in sensing elements and how to improve the anti-interference ability of sensing elements, are the aspects that requires further consideration. Aiming to improve the working quality and reduce energy consumption, further research into the tractor electro-hydraulic hitch system is necessary. The results of this comprehensive review provide a reference for the intelligent operation of tractors under the precision agriculture.

Keywords: tractor; electro-hydraulic hitch system; tillage depth adjustment; tillage depth control algorithm; key components

Citation: Sun, X.; Lu, Z.; Song, Y.; Cheng, Z.; Jiang, C.; Qian, J.; Lu, Y. Development Status and Research Progress of a Tractor Electro-Hydraulic Hitch System. *Agriculture* **2022**, *12*, 1547. https://doi.org/10.3390/agriculture12101547

Academic Editors: Muhammad Sultan, Redmond R. Shamshiri, Md Shamim Ahamed, Muhammad Farooq and Jiyu Li

Received: 31 August 2022
Accepted: 21 September 2022
Published: 25 September 2022

1. Introduction

Precision agriculture is a modern agricultural management concept developed in the 1990s, based on a series of high-tech technologies, such as modern information technology, biotechnology and engineering equipment technology. It has great advantages in improving the agricultural output, making efficient use of agricultural resources, promoting agricultural sustainable development and protecting the ecological environment [1,2]. Among these, engineering equipment technology plays an important role as the premise and basis for realizing the whole system of precision agriculture [3,4]. A tractor hitch system is the core component to complete the connection between the tractor and the agricultural machinery. On the one hand, it transmits the power of the tractors, and on the other hand, it performs the lifting and attitude control of the agricultural machinery. The tractor completes different field operations and uses different machinery to complete different field operations through the use of the hitch system. The plough unit, combined with the suspension plough, is a typical example. With the development of electromechanical integration technology, electro-hydraulic proportional control technology, sensing technology, CAN bus technology and microcomputer technology, these technologies are gradually being applied to the tractor hydraulic hitch system, which promotes the transformation of the traditional mechanical hydraulic hitch system into a more intelligent system. However, due to the complexity of the field environment and the diversity of operation types, the tractor causes large disturbances and has a strong nonlinearity in its working process [5,6]. Therefore, there are still many problems in introducing intelligent technology into agricultural production [7,8].

As an indispensable operation in agricultural production, tillage is one of the main reasons for energy consumption [9–11]. Plowing takes up more traction energy than the other operations involved in tilling [12]. Compared with the traditional mechanical hydraulic hitch system, the tractor electro-hydraulic hitch system has more working adjustment modes, which can reduce the energy consumption of the tractor ploughing unit in operation, reduce the use of fuel and improve the operation efficiency [13–15]. In addition, due to the use of the automatic control method of the working depth, combined with the high precision sensor unit, the CAN bus technology and other information technologies eliminate the use of suspension operating handles on the original tractor and these are removed. Therefore, it greatly reduces the labor intensity of drivers, improves the level of intelligence and the automation of tractors, and makes tractors more suitable for the development requirements of fine agriculture, in the future [16,17].

Operation quality is an important index to evaluate the control performance of a tractor electro-hydraulic hitch system. At present, the method of improving the control performance of a tractor electro-hydraulic hitch system by optimizing the control method, has been widely criticized. Based on the analysis of the development status and research progress of the tractor electro-hydraulic hitch system in the world, this study aims to contribute to the development of the tractor electro-hydraulic hitch system by investigating the research methods, technical characteristics and emerging trends in three key aspects, including the tillage depth adjustment method, the tillage depth control algorithm and the core components of the electro-hydraulic hitch system. Different adjustment methods can meet the complex the constraints of the working terrain and soil conditions in different regions. Using modern control theory and technology to control the operation depth, is conducive to improving the response performance of the control system. In addition, the continuous development of modern sensor detection technology and valve control technology are important means to accomplish the real-time feedback and precise control. The integration of the abovementioned technologies contributes greatly to the improvement of the operation quality and the reduction of energy consumption.

The goal of this study was to comprehensively review the existing literature related to the tractor electro-hydraulic hitch system and its key technologies. This article was based on the following aspects and organized as follows. Section 2 states the research status of the tractor electro-hydraulic hitch system at home and abroad, commenting on different types of tractor electro-hydraulic hitch systems. Then, Sections 3 and 4 discuss the development status of the different tillage depth adjustment methods and the tillage depth control algorithms. Section 5 provides a review of the key components of the tractor electro-hydraulic hitch system. Finally, in Section 6, the future development trends are given for the tractor electro-hydraulic hitch system.

2. Development Status of the Tractor Electro-Hydraulic Hitch System

In the early days, tractors completed operations through agricultural tools with traction units. Prior to 1933, the Irish scholar Harry Ferguson invented the three-point hitch device that has been widely recognized all over the world. The system is still being used and has become the standard in the industry [18]. The traditional mechanical hydraulic hitch system is a mechanical-hydraulic integrated product which makes full use of the characteristics and advantages of the hydraulic transmission. The driver adjusts the position of the distributor by operating the handle to control the direction and flow of the hydraulic oil to adjust the lifting and lowering of the agricultural machinery. It has the advantages of low design and manufacturing costs [19,20]. The structure principle is shown in Figure 1.

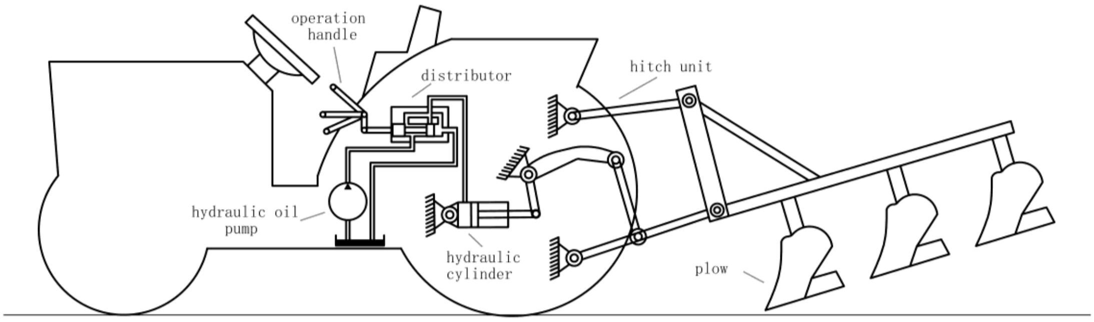

Figure 1. The structure principle of the traditional mechanical hydraulic hitch system.

However, due to the complex structure of the system, it is not only difficult to assemble, but also difficult to maintain once damage occurs. Furthermore, because of the deformation of the mechanical mechanism and the hysteresis of the elastic element itself, it is unable to ensure a good quality of operation, and does not adapt to the developing trend of precision agriculture. With the development and maturity of electronic technology and microcomputer technology, scholars in China and abroad began to study the tractor based on the integrative technology of mechanics-electrics-hydraulics. The traditional mechanical hydraulic hitch system is gradually being replaced by the modern electro-hydraulic hitch system. Figure 2 shows the structural principle of the modern electro-hydraulic hitch system.

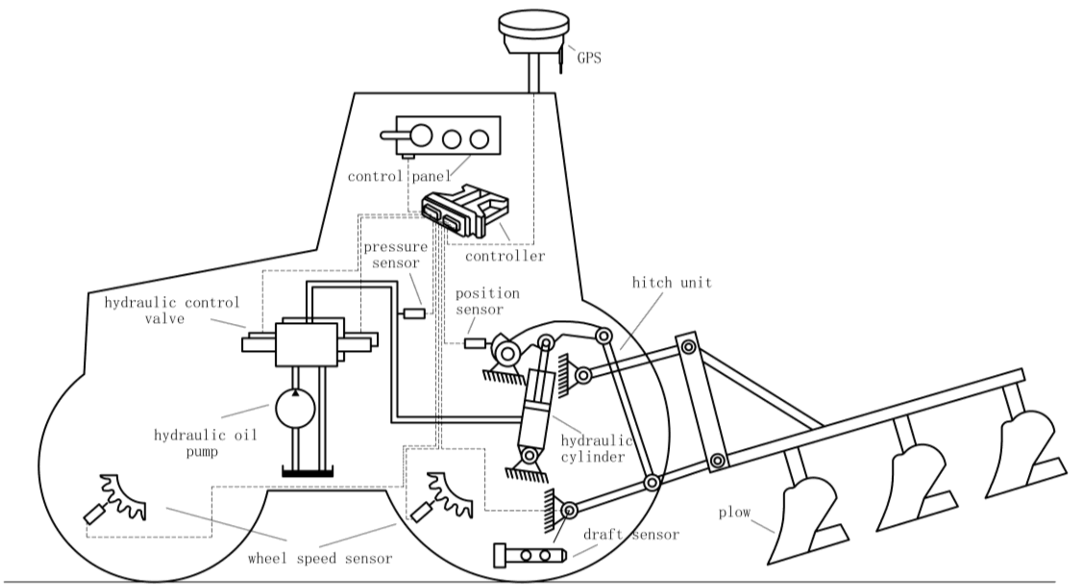

Figure 2. The structure principle of the modern electro-hydraulic hitch system.

2.1. Basic Types of Hitch Systems

The tractor hitch system is mainly composed of an oil pump, a distributor (hydraulic control valve) and a hydraulic cylinder. According to the installation positions of the three main hydraulic components, they are divided into three types: split type, integral type and semi-split type [21]. Table 1 shows the comparison of the different hitch systems

Table 1. Comparison of different hitch systems.

Type	Layout Characteristics	Advantages	Disadvantages	Application of the Tractor
Split	Pumps, distributors (hydraulic control valves) and cylinders are installed at different locations	Flexible layout, Easier maintenance, Easy to be standardized	Complex connection pipeline, Easy to leak	Dongfanghong-75 (YTO, Luoyang, China) TN-55 (TT, Tianjin, China) M1304-R (LOVOL, Weifang, China)
Semi-split	Distributor (hydraulic control valve) and cylinder installed together, pump arranged separately	Compact structure	Inconvenient to fault check	TM130 (New Holland, WI, USA) 800 (CF, Changzhou, China)
Integral	Oil pump, distributor (hydraulic control valve) and oil cylinder are installed together	Compact structure, good sealing	Complex structure, big volume, Difficult to standardize	T8000 (New Holland, WI, USA) 35 (FS, Shanghai, China)

2.2. Development Status of the Electro-Hydraulic Hitch System in Foreign Countries

Foreign scholars began to study the electro-hydraulic hitch system in the 1970s. In 1978, Germany's Mercedes Benz first applied the electro-hydraulic hitch system to its agricultural tractor, marking the successful application of the electro-hydraulic control technology in the field of agriculture [22]. Subsequently, the Toshiba Corporation of Japan developed an IC electro-hydraulic hitch control system with the position regulation function. This system can not only adjust the depth of the rotary tillage operation, but also automatically adjusts the posture of the agricultural machinery in order to reduce the influence of the left and right tilts of the agricultural tools on the quality of its operation [23]. In 1986, Bosch developed the CAN bus technology and for the first time it was applied to the tractor control system by Scarlett in the early 1990s, which effectively improved the quality of the tillage depth and reduced the operating intensity of the tractor drivers [24,25]. Major foreign universities have also conducted in-depth research into the electro-hydraulic hitch system, they have designed electro-hydraulic hitch systems to meet different needs, and have verified the feasibility of their design scheme through experiments. For instance, Kyoto University in Japan, the University of the Witwatersrand in South Africa and The Technical University of Braunschweig in Germany [26–28].

The tractor electro-hydraulic hitch systems designed in foreign countries after years of development, have formed a more mature product. Major companies such as Bosch–Rexroth [29], Walvoil [30] and Danfoss [31] have launched similar electro-hydraulic hitch systems. At present, the leading position in the foreign market is the tractor electro-hydraulic hitch control system (EHC) introduced by Bosch–Rexroth. This system is mainly composed of a controller, operating panel, hydraulic pump, hydraulic cylinder and a solenoid valve. With a wheel speed sensor, force sensor, displacement sensor, pressure sensor, radar and other sensors. Each electronic control unit on the tractor transmits data through the CAN bus, which makes the tractor have a high operation efficiency and good operation coordination ability. This system meets various functions such as force control, position control, pressure control, slip rate control and force-position integrated control. Drivers only need to select the appropriate working mode through the operating panel according to the actual operating requirements. Experiments show that compared with the existing mechanical hydraulic control system, the slip rate achieved using the EHC system is reduced by 7–30%, the energy consumption of the whole machine is reduced by 2–3% and the work efficiency is improved by 3.4–3.8% [18]. Therefore, at present, most tractors in western countries have applied the system from companies such as John Deere, DEUTZ, New Holland, etc.

2.3. Development Status of the Electro-Hydraulic Hitch System in China

Due to the late start of the tractor industry in China, the tractor hitch technology is relatively backward. In the 1980s, foreign famous brands of tractors, such as John Deere, Fiat and so on, were introduced in China. The tractor hitch technology in China has since improved. Following the 1990s, with the rapid development of electronic technology, many universities in China began to study the electro-hydraulic hitch system of tractors.

Zhan et al. [32] used a single chip microcomputer for the control of the tractor hitch system. Taking the tractor ploughing unit as the research object, the mathematical model of each part was established, and the simulation operation was completed. In this study, several problems regarding the digital simulation of the tractor electro-hydraulic hitch system through the use of a microcomputer were discussed. Fang et al. [33] changed the valve core of the Jangsu-50 tractor (YTO, Luoyang, China) distributor into an electromagnetic drive and established a closed-loop feedback control system by installing angle sensors. The accuracy of the control system was proved using the comparison test with the traditional mechanical feedback system.

In the 21st century, more new technologies, such as electronic technology and computer control technology, have been applied to the tractor electro-hydraulic suspension system. China has achieved fruitful results in the study of the tractor electro-hydraulic suspension control system. Xie et al. [34] reformed the traditional mechanical hydraulic hitch system, replaced the distributor with electro-hydraulic proportional valve and achieved the digital control through a single chip microcomputer. The good performance of the improved suspension system was verified through an experiment. Later, Xie et al. [35] also carried out the research on the application of the CAN bus in the electro-hydraulic hitch system. At the same time, large tractor enterprises in China also carried out a series of studies for the tractor hitch system. For example, YTO, Lovol and Dongfeng et al. have launched intelligent tractor products with a variety of working modes. The technical characteristics of the hydraulic suspension type of some tractors are shown in Table 2.

Table 2. Types and Technical Characteristics of Hydraulic Suspension Systems in China.

Model	Company	Type	Adjustment Mode	Maximum Lifting Force (kN)
M604-E	LOVOL	semi-split	Position, Draft, Mixed draft-position adjustment	≥10.1
LF1504	YTO	semi-split	Position, Draft, Height, Mixed draft-position adjustment	≥28
M2204-R	LOVOL	split	Position, Height, adjustment	≥39
CFK1804	Changfa	split	Position, Draft, Height, Mixed draft-position adjustment	≥42

3. Research Progress into the Tillage Depth Adjustment Methods

Due to the complexity and diversity of the tractor field working environment, it is often necessary to adjust the tillage depth repeatedly to obtain a stable and uniform tillage depth. Therefore, the development of the tillage depth adjustment method is a necessary means to obtain an accurate and efficient adjustment. In the early stage, the mechanical hydraulic hitch system was generally adjusted manually by adjusting the operating handle, which was not only inefficient but also poor in quality. With the development of the electro-hydraulic hitch system, the tillage depth adjustment method has gradually changed from the manual adjustment to the automatic adjustment. Currently, there are three major ways to adjust a tractor's tillage depth: by a single parameter adjustment, mixed draft-position adjustment and mixed draft-position-slip adjustment.

3.1. Method of the Single Parameter Adjustment

The single parameter adjustment method adjusts the position of the three-point hitch device with a single parameter as the main control index, so as to obtain the desired effect. This way can be well targeted for different terrain characteristics. At present, there are two kinds of single parameter adjustment methods: the position adjustment and the draft adjustment.

According to the position regulation principle of the tractor electro-hydraulic hitch system, Chen et al. [36] designed the position regulation controller based on a microcontroller and a displacement sensor and verified it on the simulation test bench. The experimental results showed that the system had an anti-disturbance ability and could achieve automatic control. However, this study only carried out the position adjustment control in the simulation state, and the control effect needs further experimental verification [36]. Based on the CAN bus technology, Zhang et al. [37] proposed an adjustment scheme with the PLC as the core, according to the technical requirements of the system. In order to verify the feasibility of the scheme, the lifting and lowering experiments were carried out by using Simulink. However, the simulation test condition in this study were too ideal to consider the interference problem in the actual operation process. In addition, Lee et al. [38,39] and Xia et al. [40], based on the displacement sensor feedback of the tillage depth for the position adjustment, also increased the inclination sensor to measure the attitude of the farm tool. In the study by Xia et al. [40], the test results showed that the maximum coefficient of variation of the tillage depth under each working condition was 4.28%. This method had a good correction effect on the tillage depth error caused by uneven road surfaces.

Hao et al. [41] built a tractor electro-hydraulic hitch system model based on AMESIM and ADAMS. The force regulation simulation was carried out under soil disturbance conditions. The simulation results showed that the adjustment error of the hitch system is within 1.7%. It provided a reference for the construction of the joint simulation platform. However, the accuracy of the simulation model still lacks verification. Chen et al. [42], Wang et al. [43] and Xu et al. [44] analyzed the advantages and disadvantages of the original mechanical hydraulic hitch system with the draft adjustment method, proposed the draft adjustment scheme of the electro-hydraulic hitch system based on a single chip microcomputer, and built the indoor bench to test and verify the feasibility of the scheme. However, due to the limited conditions, there was a certain deviation between the simulated loading and the actual working conditions of the loading system, which needs to be further improved, according to the field test. Zhang et al. [45] studied the prediction of the tillage resistance in the process of the draft adjustment. Aiming at the problem of a low prediction accuracy of the tillage resistance in the process of the draft adjustment, the nonlinear modeling method based on ANFIS was used to construct the prediction model of the tillage resistance in the process of operation, and the adaptive adjustment was realized. The accuracy of the method was verified by field experiments.

3.2. Method of the Mixed Draft-Position Adjustment

The mixed draft-position adjustment is a comprehensive adjustment method that combines the uniformity of the tillage depth of position adjustment and the stability of the engine traction load with the draft adjustment. At present, the mixed draft-position adjustment method generally adopts two forms, the switching method and the weighted coefficient method. The former allows to switch between the position adjustment and the draft adjustment, according to soil changes, and the latter adds the two adjustment methods according to a certain weight.

Shang et al. [46] applied the switching method and the weighted coefficient method to the comprehensive adjustment of the force and position. Through a simulation verification, it was concluded that the weighted coefficient method had more long-term research and application value. Zhao et al. [47], Xu et al. [48] and Guo et al. [49] studied the weight coefficient of the mixed draft-position adjustment method, but they were limited to the comparative analysis of the artificially set weight coefficient.

Li [50] proposed a mixed draft-position adjustment scheme with variable weights (Figure 3). In the adjustment process, the weight of the initial draft adjustment was preset by the driver, and then the weight was corrected according to the actual operation situation. In the areas with uniform soil change, the weight of the draft adjustment is reduced to ensure the tillage quality of tractors. Conversely, the weight is increased to ensure that the tractor can pass in the areas with large soil changes. The effectiveness of the scheme was verified by simulation and experiment. However, since the initial weight and weight adjustment of the scheme still need to be set manually by the driver, the adjustment efficiency is not high.

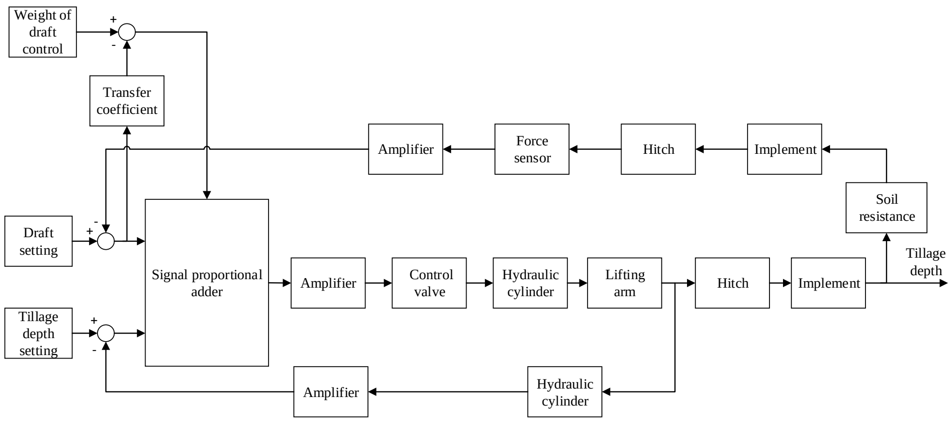

Figure 3. Mixed draft−position adjustment scheme with variable weights.

Based on the consideration of the influence of the soil specific resistance on the weight coefficient, Wang et al. [51] established the relationship model between the weight coefficient and the soil specific resistance. Then, a variable weight mixed draft-position adjustment method based on the soil specific resistance was designed. According to the simulation data and a large number of field operations, the approximate relationship between the weight coefficient and the soil specific resistance was obtained. This method can automatically adjust the weight coefficient according to the soil specific resistance, which improves the operation effect of the tractors in areas with large changes in soil specific resistance.

3.3. Method of the Mixed Draft-Position-Slip Adjustment

The three-parameter comprehensive adjustment of the draft-position-slip is a kind of adjustment method that introduces the sliding rate on the basis of the mixed draft-position adjustment. On the one hand, this method can obtain a stable power output on the basis of ensuring the tillage depth uniformity; on the other hand, because of the high traction efficiency of the tractor, it can obtain a good fuel economy [52]. At present, there are two forms of the method of the mixed draft-position-slip adjustment, the weighted coefficient method and the logic threshold method.

Gao [53] designed a three-parameter comprehensive adjustment scheme based on the weight coefficient method. The adjustment logic is shown in the Figure 4. In his research, the output of the draft-position adjustment and the slip adjustment were weighted according to a certain proportion to form a total output. Adjusting the weight of the two ratios can change the ratio of resistance, position and slip in the adjustment process. The proportion of the draft, the position and the slip involved in the adjustment process can be changed by adjusting the weight of the two proportions. The principle of this method is simple, but the weights of the two proportions are subjectively set by the driver, and the adjustment has a certain randomness.

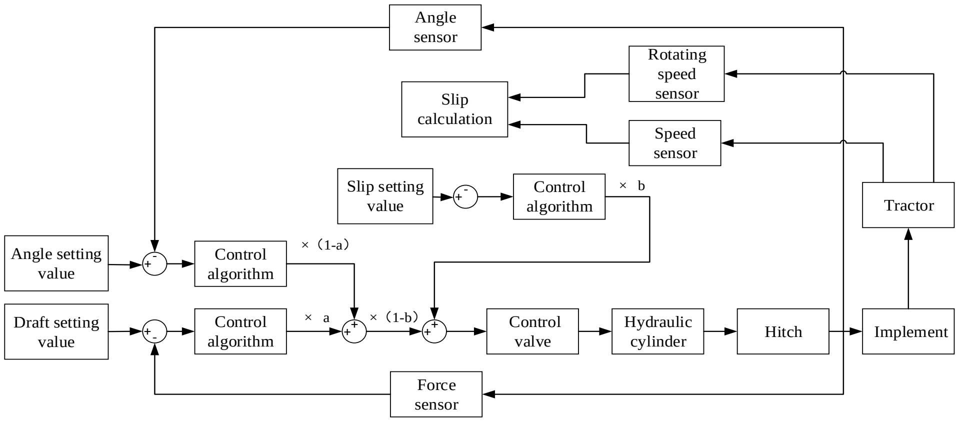

Figure 4. Three−parameter comprehensive adjustment scheme based on the weight coefficient. a. Weight of position adjustment; b. Weight of slip adjustment.

Ma et al. [52], Mu et al. [54] and Bai et al. [55], designed a three-parameter comprehensive adjustment scheme based on the logic threshold method. The adjustment logic is shown in the Figure 5. The principle of this scheme is that in the tillage process, the system will calculate the slip rate in real time, and when the slip rate is within the set threshold range, the system enters the mixed draft-position adjustment; When the slip ratio exceeds the set threshold range, the system enters the slip adjustment until the slip ratio is adjusted to the optimal range and then enters the mixed draft-position adjustment again, so the different adjustment modes are switched in this cycle. The results showed that this scheme not only ensured the traction efficiency of the tractor, but also obtained good uniformity of the tillage depth [52]. However, in the actual operation process, it is difficult to achieve a real-time accurate measurement of the slip rate due to the complex force of the tire and the sensitive change of the slip rate.

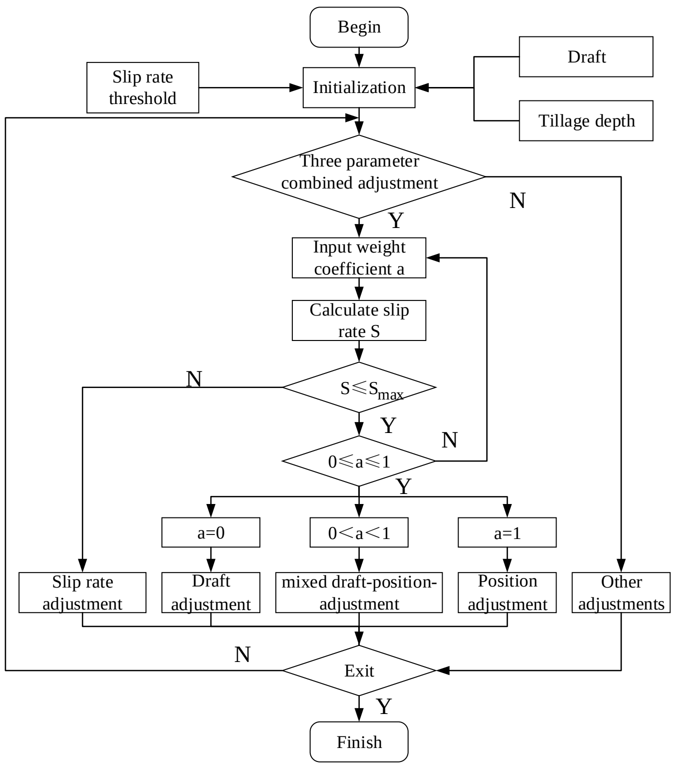

Figure 5. Three−parameter comprehensive adjustment scheme based on the logic threshold.

In summary, the method of the single parameter adjustment is simple and convenient, but it is difficult to ensure the quality of the operation for the complex and changeable field working conditions. For example, in the uneven terrain area, the position adjustment does not have a profiling function; the draft adjustment causes a poor stability of the tillage depth in areas with large soil changes. Compared with the method of the single parameter adjustment, the method of the mixed draft-position adjustment can adapt to a variety of working environments and improve the working quality. Among them, the weighted coefficient method has more long-term research and practical value. However, there are still some problems, on the one hand, the weighting coefficient is affected by human factors, on the other hand, the adhesion conditions in the process of the tractor operation are not considered. In addition, although the method of the mixed draft-position-slip adjustment combines the advantages of the different methods, due to the difficulty in the real-time measurement and the calculation of the slip rate of the driving wheel in complex working environments, and whether the method of the mixed draft-position-slip adjustment can achieve seamless coupling, remains to be verified. This method needs further research [56]. Different adjustment methods have their own advantages and scopes for use, but they also have their own shortcomings. In order to understand the characteristics of the different adjustment methods more intuitively, the comparison table of the different adjustment methods is shown in Table 3.

Table 3. Comparison of the different tillage depth adjustment methods.

Item	Position Adjustment	Draft Adjustment	Draft-Position Mixed Control	Draft-Position-Slip Mixed Control
Engine load stability	Bad	Best	Good	Best
Traction efficiency	Bad	Good	Good	Best
Operation quality on different soils	Good	Bad	Good	Best
Operation quality on rough surface	Bad	Good	Good	Best
Application	Shallow tillage	Deep tillage	All operation	All operation

4. Research Progress of the Tillage Depth Control Algorithm

In order to improve the stability and accuracy of the tillage depth control of the tractor electro-hydraulic hitch system, researchers also tried to start from the control algorithm and achieved certain results. The current research is mainly divided into the classical control algorithm represented by the PID control and the intelligent control algorithms.

4.1. PID Control Algorithm of the Tillage Depth

The PID control is one of the earliest developed control algorithms. It is widely used in the industrial controls because of its simple structure and strong adaptability [57]. The key to the creation of the PID control algorithm lies in the establishment of the mathematical model of the control system and the tuning of the PID parameters.

The essence of the tractor electro-hydraulic hitch control system is to control the spool displacement of the hydraulic valve so as to achieve the lifting and lowering of the agricultural tools. So, the mathematical model of the hydraulic system can be used to analyze the characteristics of the PID controller. Relevant scholars established the general transfer function of the tractor electro-hydraulic hitch system, as shown in Equations (1) and (2) [34,58–60].

$$\frac{Y(s)}{X(s)} = \frac{K_q/A}{\frac{MV_t}{4\beta_e A^2}S^3 + \left[\frac{MK_{ce}}{A^2} + \frac{B_p V_t}{4\beta_e A^2}\right]s^2 + \left[1 + \frac{B_p K_{ce}}{A^2} + \frac{K_t}{4\beta_e A^2}\right]s + \frac{K_L K_{ce}}{A^2}} \tag{1}$$

$$\frac{Y(s)}{F_L(s)} = \frac{-K_{ce}\left[1 + \frac{V_t}{4\beta_e K_{ce}}s\right]}{\frac{MV_t}{4\beta_e A^2}S^3 + \left[\frac{MK_{ce}}{A^2} + \frac{B_p V_t}{4\beta_e A^2}\right]s^2 + \left[1 + \frac{B_p K_{ce}}{A^2} + \frac{K_t}{4\beta_e A^2}\right]s + \frac{K_L K_{ce}}{A^2}} \tag{2}$$

Among it: Y is the displacement of the hydraulic cylinder, m; X is the displacement of the spool, m; F_L is the external load; K_q is the valve flow co-efficient; A is the area of the hydraulic cylinder, m^2; M is the inertia mass, kg; V_t is the fluid volume, m^3; K_{ce} is the total leakage co-efficient; β_e is the bulk modulus of the oil, Pa; B_p is the viscous co-efficient of the fluid, N·s/m.

Zhang [37] took the hydraulic hitch system of a DF354 tractor (DFAM, Changzhou, China) as the research object and established the mathematical model. Then, the step response characteristics were simulated and analyzed (1) without the use of a PID control, (2) with a proportional controller, (3) with a proportional-integral controller and (4) with a PID controller. Finally, the response rise time of the system was 0.0298 s, and the adjustment time to reach the set value was 0.179 s. This study provides a theoretical basis for the design of the actual system. However, the system only performs a simulation verification under the position adjustment, thus lacking any field test verification and the interference problem in the actual operation process was not considered.

Li et al. [61] and Li et al. [57] took the tillage depth control system of the rotary cultivator as the research object, and the simulation model of the electro-hydraulic hitch system was built using the SIMHYDRAULIC module in MATLAB. Aimed at solving the problem concerning the system's overshoots and oscillation, an integral separation PID control system was proposed and simulated. The simulation results showed that the amount of time to achieve the stability using the integral separation PID control algorithm, was 3.6 s less than that without the PID control. Zhou et al. [62] introduced a neural network algorithm to design the variable-gain single-neuron PID controller for the conventional PID controller that has no self-learning and adaptive abilities. In the face of the strong time-varying field conditions, the PID parameters can be adjusted according to the environmental changes. The robustness and adaptability of the tillage depth control system were greatly enhanced.

4.2. Intelligent Control Algorithm of the Tillage Depth

Zadeh first proposed the concept of the membership function in his 'fuzzy sets' and created the fuzzy set theory in 1965 [63]. The British scholar Ebrahim Mamdani applied the fuzzy set theory to the steam engine control, and built one of the first fuzzy control systems to control a steam engine together with a boiler, in 1974 [64]. It was a modern intelligent control algorithm with artificial thinking based on the fuzzy mathematics language. Pang [65] first introduced the fuzzy control into the tractor electro-hydraulic hitch control system. The integrated control simulation model, based on the engine load rate, driving wheel slip rate and operating resistance was established and the discontinuous variables and continuous variables of the fuzzy control algorithms were designed, respectively. It was verified by comparison that the automatic control was more accurate than the manual experience control.

In order to improve the accuracy of the tillage depth of the control system, Lu et al. [66] designed a tractor tillage depth fuzzy controller and developed a fuzzy control rule table of the electronically controlled hydraulic hitch system. Figure 6 shows the fuzzy control principle diagram of the tillage depth. The bench verification results showed that the response time of the tillage depth to the specified target was less than 1.7 s, and the maximum error of the tillage depth was ±1cm. This method reduces the influence of surface roughness disturbance and the parameter variation on the control effect. The feasibility of applying the fuzzy controller to the tractor electro-hydraulic hitch system was verified.

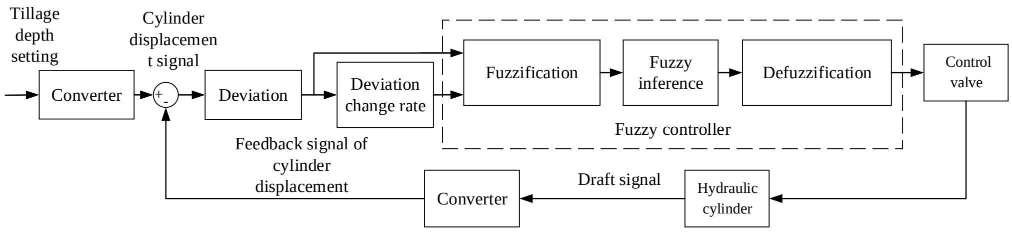

Figure 6. Principle diagram of fuzzy control algorithm.

Serhat et al. [67] took the slip rate of the driving wheel as the system input, and designed a tractor slip rate controller based on the fuzzy control. Then, the adjustment of the tillage depth was determined based on the fuzzy rules, and the effectiveness of the control system was verified by field experiments. Han et al. [68] proposed a draft-position mixed control strategy for the electro-hydraulic hitch system and designed a fuzzy controller based on a Jinma 1204 tractor (Yueda, Yancheng, China). The experimental results showed that the ploughing depth error was less than ±2 cm, but the system response time was 4.8 s. However, the designed controller's processing speed needs to be further improved. Tan et al. [69] and Gao et al. [70] compared the PID controller and the fuzzy controller. In the study by Tan [69], the PID control was more accurate than the fuzzy control, but the system was always within regulation and unstable. The fuzzy control did not adjust when the deviation was small, which was beneficial to the system energy saving. However, this conclusion lacks the verification of field experiments. Using a Dongfanghong-1604 tractor (YTO, Luoyang, China), an experiment verification was carried out by Gao et al. [70]. The results showed that the tillage depth error was controlled within 2 cm. Compared with the PID control, the fuzzy control had a shorter response time and a smaller response curve amplitude. However, they only studied the position control, and did not consider the influence of the road roughness and soil specific resistance.

Shafaei et al. [71] developed a tractor fuzzy draft-position control system and wrote a set of instructions containing four fuzzy rules. In order to verify the characteristics of the control system, the field experiments were designed at three tillage depth levels (10, 20, 30 cm), three forward speeds (2, 4, 6 km/h) and with three plow types (plow plate, disc plow, chisel plow) and compared their results with the original MF399 tractor control system. The test results showed that the application of the fuzzy control increases both the tractor traction efficiency and the overall energy efficiency by up to 20% and 73%, respectively, the tillage depth error, the driving wheel slip rate, and the fuel consumption were decreased by 53%, 34% and 34%, respectively. In addition, the study showed that the tillage depth and plow type have no effect on the control performance, and the forward speed had an effect on the control performance of the system ($p \leq 0.01$). Therefore, in future studies of the electro-hydraulic hitch system, the working speed of the tractor needs to be considered.

In order to combine the advantages of the different algorithms, Li et al. [72] introduced the fuzzy control theory into the PID control and designed a fuzzy PID adaptive controller. As shown in Figure 7, the principle was to calculate the PID parameters by fuzzy inference, and then output the control signal by the PID. The simulation and experimental verifications were carried out under the position control and the draft control. The simulation results showed that the transition time of the fuzzy PID adaptive control was reduced by 15.5 s compared with the conventional PID under the position control, and the system had no overshoot. Under the draft control, the transition time of the fuzzy PID adaptive control was reduced by 2.8 s compared with the conventional PID, and the system changed smoothly without oscillation. The experimental results showed that the fuzzy PID adaptive control effect was basically consistent with the simulation in the position control, but it was worth noting that the overshoot of the system reached 25% in the position control mode.

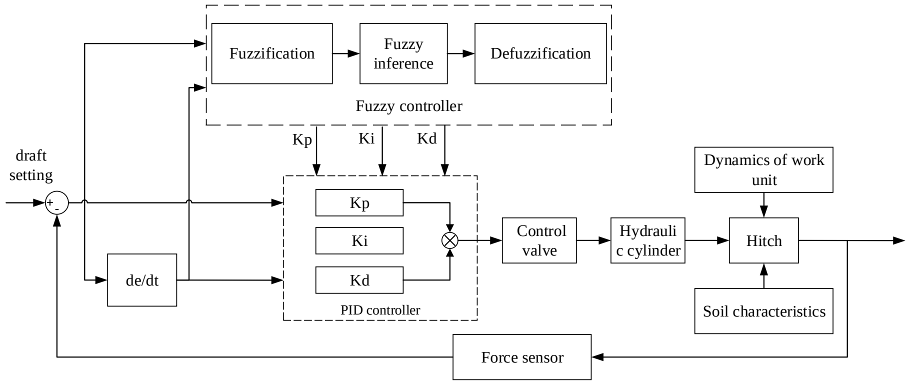

Figure 7. Principle Diagram of the Fuzzy−PID Control Algorithm.

Wang et al. [73] introduced the variable universe fuzzy PID control in the tillage depth control. The simulation platform of the draft-position mixed control was established based on MATLAB and the system characteristics when using a PID controller, a fuzzy PID controller and a variable universe fuzzy PID controller were simulated and compared. The results showed that the PID control results have 19.2% overshoot and the system response time was 1 s. The fuzzy PID control results had no overshoot, and the response time was reduced by 0.1 s compared with the PID control. There was no overshoot in the variable universe fuzzy PID control, and the response time was reduced by 0.44 s compared with the fuzzy PID control. This study provided a method for the selection of the initial domain in the fuzzy control. However, due to the constraints of the conditions, the experiments were carried out only under one single soil specific resistance, and there was a lack of verification of the simulation results.

In addition to the above algorithm, Zhang et al. [74] introduced a more advanced sliding mode variable structure controller algorithm. The dynamic model of the tractor ploughing unit was established, and a comprehensive control strategy of the slip rate, based on the tractor traction characteristics, was proposed. The comparison with the fuzzy PID control showed that the average absolute deviation of the tractor slip rate, the variation of the tillage depth adjustment and the variation of the draft adjustment were reduced by 27%, 27% and 42% when using the sliding mode variable structure controller algorithm. The control performance and superiority of this way were verified. There was a concern in this study. The derivation of this method involved many physical quantities, and most of them were difficult to obtain directly through measurement. However, it should be worth noting that this study was an exploration of the application of future intelligent algorithms in electro-hydraulic hitch systems.

In summary, with the continuous development and maturity of the advanced control theory, in the study of the tractor tillage depth control algorithm, researchers have not only been limited to the simple PID control, but also transformed it into a control mode combining multiple control algorithms. With the introduction of intelligent algorithms, the response characteristics and control accuracy of the tillage depth control system are greatly improved.

5. Research Progress of Key Components of the Electro-Hydraulic Hitch System

Compared with the traditional mechanical hydraulic hitch system, in order to obtain a good working quality and to reduce energy consumption, the electro-hydraulic hitch system not only adopts advanced control methods, but also constantly updates and develops the composition hardware. Among them, the control valves and sensing elements, as the core components, have attracted wide attention from scholars in China and abroad.

5.1. Hydraulic Control Valve

The hydraulic control valve is the core component of the tractor electro-hydraulic hitch system. The early commonly used control valve is the mechanical control valve, generally of the slide rod type, through which the operation handle drives the slide rod movement, so as to realize the oil circuit connection and closure. With the development of the electro-hydraulic proportional control technology, the electro-hydraulic proportional valve is gradually used in the tractor electro-hydraulic hitch system. A large number of research results on the design of hydraulic control valve of tractor electro-hydraulic hitch system have been accumulated by relevant scholars. A comparison of several typical schemes is shown in Table 4.

Table 4. Comparison of the hydraulic control valves with different principles.

Scheme	Structure	Control Mode	Features
1 [75]	Rotary type	Motor control	Proportional valve, Single-acting
2 [41,76,77]	plate design	Direct electromagnetic actuation	Proportional valve, Single-acting, With load sensitive
3 [78]	threaded cartridge	Pilot control	Proportional valve, Single-acting, With load sensitive, With position feedback

The scheme 1 consists of a three-position four-way directional valve and a safety valve. The working oil port is connected with the hydraulic cylinder. The pressure relief valve is used to control the maximum working pressure of the whole system and improve the safety of the system. Three four-way directional valve to change the flow direction of oil, and the lifting and lowering of the agricultural machinery are controlled by the motion of the oil cylinder. The structure and principle of scheme 1 is simple, but the tractor electro-hydraulic hitch system using this scheme needs a separate oil supply, which cannot carry out the simultaneous operations of the multiple actuators. The scheme 2 chooses to realize the lifting and lowering of the agricultural machinery through two valves separately, and adds a pressure compensator and shuttle valve to the system. Pressure compensator is used to maintain the stability of the pressure difference in the process of operation, so that the flow of the control valve is only related to the opening of the valve port. Therefore, the operation depth of tractor electro-hydraulic hitch system can be controlled by controlling the displacement of spool. The shuttle valve can be matched with a load sensitive pump to achieve the function of the load sensitive. On the one hand, the flow can be adjusted on demand through the system pressure change fed back by the shuttle valve, so that the energy loss of the whole system is reduced. On the other hand, the load independent flow distribution can be realized, which can work with other actuators and does not require a separate oil supply. The scheme 3 is a hydraulic control valve based on pilot control, which can meet the demand of large flow control. At the same time, this scheme is equipped with a spool displacement sensor in addition to the load sensing function. The spool stroke is fed back to the control unit through the displacement sensor, and the control unit controls the spool position through the current of the pilot valve, which improves the control accuracy of the entire control valve.

Scholars have also invested a lot of theoretical research on hydraulic control valves. Li et al. [79] designed the proportional lift valve of the electro-hydraulic hitch system of the high-power tractor, and the flow characteristics of four different types of regulator orifices were analyzed. The results showed that the valve core with the half-round regulator orifice had a shorter travel and better low-flow rate characteristics. Zhao et al. [80] took the multi-way reversing valve as the research object. Then, the state equation of the multi-way reversing valve was establish based on the theoretical analysis and the performance of the multi-way reversing valve was verified by building a hydraulic system test platform, based on closed-center load sensing. Based on the state space method of the modern control theory, Hua et al. [81] established the nonlinear mathematical model of the proportional lift valve. The performance was verified by simulation and bench tests, which provided a reference for the theoretical research method of the control valve of the electro-hydraulic hitch system.

5.2. Sensor

The sensor is an essential detecting element for the tractor electro-hydraulic hitch system. As the key component of the control system, the sensors provide feedback signals for the control system, so as to realize the closed-loop control of the tillage depth. Therefore, the type and performance of the sensors directly affect the performance of the control system. For the different control modes, the types of sensors selected are also different. At present, there are two kinds of sensors most widely used in the tractor electro-hydraulic hitch system: the displacement sensor and the draft sensor. Figure 8 shows the schematic illustration of the installation of the sensors.

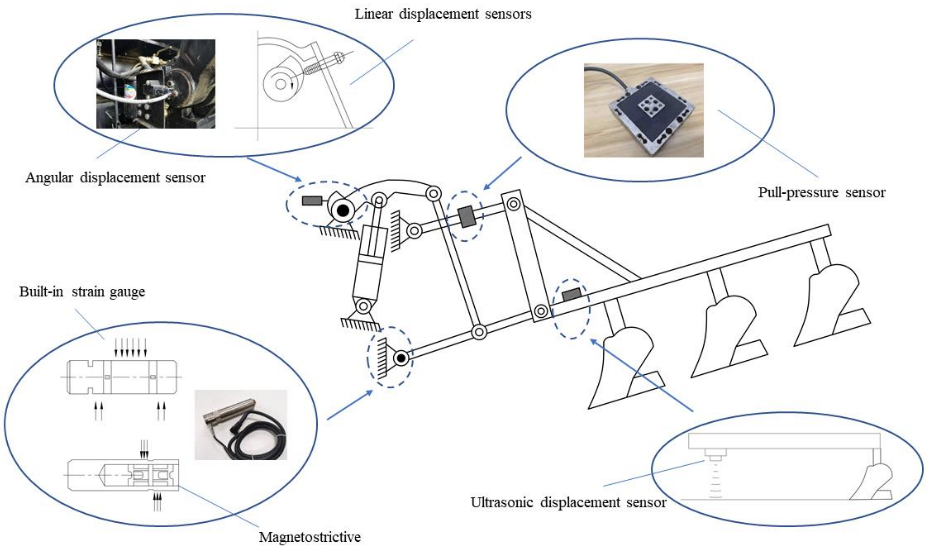

Figure 8. Schematic illustration of the installation of the sensors.

5.2.1. Displacement Sensors

The displacement sensors are mainly used to feedback the tillage depth in real time in the process of controlling the operation depth by the electro-hydraulic hitch system. Currently, there are mainly two different types according to the measurement method: contact and non-contact.

Adamchuk et al. [82] and Li et al. [83] used a non-contact ultrasonic displacement sensor to feedback the tillage depth. The sensor mainly uses the uniform transmission of sound waves to obtain the measured distance by calculating the time interval and sound velocity between the sound waves emitted and received. The study by Li [83], compared the resistance displacement sensor with the accuracy of the ultrasonic displacement sensor, which was higher than that of resistance displacement sensor.

A swinging arm type of frame height sensor was designed to measure the distance variation between the soil surface by Mouazen et al. [84]. The sensor was mainly composed of a metal wheel and a linear variable displacement sensor connected with the metal wheel shaft. An analytical–statistical hybrid model was developed based on the kinematics analysis and the tests were performed on four surfaces: asphalt road; rough dirt track; and agricultural silty clay loam soil (bare soil and soil with stubble present). The results showed that compared with the ultrasonic sensor, the sensor can reduce the influence of plant residues and stubble on the measurement results. However, due to the existence of a certain weight of the metal wheel, there would be subsidence in the wet and soft ground, which affects the accuracy of the measurement results.

MacQueene et al. [85] used inductive linear displacement sensors to obtain the tillage depth. The inductive linear displacement sensor is an electromagnetic inductive displacement measuring element, its principle mainly uses the self-inductance or mutual inductance of the coil inside the sensor to convert the displacement signal of the measured object into an electrical signal for the output [86]. In this study, a cam disc was installed on the lifting arm to convert the rotation angle signal into a linear displacement signal, and then the inductive displacement sensor was used to measure the stroke of the cam. According to the kinematic relationship between the rods of the three-point suspension device, the rotation angle of the lifting arm was converted into the height of the farm tool. The principle of this method is simple, but the installation position of the cam and the adjustment convenience of the linear displacement sensor should be considered in the use process. Cai et al. [87] replaced the linear displacement sensor with the angular displacement sensor based on similar principles to measure the angle of the lifting arm directly. Due to its simple installation and accurate measurement, it is widely used in current research.

5.2.2. Draft Sensors

The draft sensors are designed to measure the draft exerted by farm implements on the tractor drawbar. According to the different measurement positions, these are grouped into two major categories: the drawbar dynamometers and the three-point hitch dynamometers [88].

Zhang et al. [89] and Bentaher et al. [90] used the upper link with a pull-pressure sensor and an angle sensor to replace the original upper link of the tractor and to it connect with agricultural machinery. Then, the horizontal and vertical drafts can be obtained by the force and angle of the upper link. Kumar et al. [91] and Roul et al. [92] installed an annular sensor based on the principle of strain gauge and a rotary potentiometer to achieve the draft measurements. However, the above studies need to reform the upper link, so it has not been widely applied. Bhondave et al. [93] directly used the sense implement load via the top link of the three-point linkages by the axial pin draft sensor. This method is more convenient because it does not need to modify the structure of the upper link. However, it should be worth noted that Gao et al. [94] studied the characteristics and the quality of the draft signals in two sensing methods of the upper links and lower links under different tillage conditions. The dynamic model of the three-point hitch mechanism was analyzed, and the results showed that the absolute error of the lower link measurement was smaller than that of the upper link measurement. Therefore, the lower links measurement method should be used to improve the measurement accuracy.

A draft sensing pin was used to attach the lower links to the implement by Singh et al. [95] The principle of the sensor is to use the deformation of the resistance strain gauge inside the sensor to generate the differential pressure signal, so as to convert the force signal of the measured object into an electrical signal for the output. Li et al. [96] proposed a special sensor to achieve the draft measurements for the electro-hydraulic hitch system of the high horsepower tractor. The sensor was based on the magneto-strictive effect. When the sensing element is subjected to force, the internal permeability changes to produce voltage. Compared with the strain gauge sensor, the sensor has a good anti-interference ability. However, the sensors can only withstand the shear force in one direction. Therefore, the accuracy of the measurement results may be affected by the direction offset when the three-point hitch mechanism moves. Based on Li's study, Li [97] designed a new kind of structure which changed the excitation magnetic core from columnar to cruciform. For the design, the mechanical dimensions were changed from 2D to 3D which can be more adaptable for a bad working environment.

Kheiralla et al. [98] and Al-Jalil et al. [99] designed a three-point hitch dynamometer with a similar structure. The force sensor consists of three sliding arms, which can adjust the position by sliding. There is an inverted U-shaped cantilever beam at the end of each sliding arm, and the two strain gauges are installed on each cantilever to form a Wheatstone bridge. The dynamometer was used to connect the tractor to farm implements, so as to measure the horizontal and vertical drafts of the farm implements.

In the existing electro-hydraulic hitch control system, the angular displacement sensor and shaft pin force sensor are widely used because of their low cost, simple working principle and convenient installation. However, there are still some problems. The accuracy and stability of the force sensor will be affected by the harsh working conditions in the field, the vibration of the farm implements, the weight of the hitch system and the asymmetry of the force. In addition, the angular displacement sensor converts the angle of the lifting arm into the tillage depth, but there are still many connecting links of the three-point hitch system between the lifting arm and the farm implements. The driver may adjust the length of the connecting links in the actual operation process, so that the geometric parameters of the three-point hitch system are changed, resulting in inaccurate results of the tillage depth. Therefore, more exploration is needed to find more suitable methods.

6. Conclusions and Prospects

The tractor electro-hydraulic suspension system can reduce labor intensity and improve comfort. The tractor can work in the best conditions by automatically adjusting the tillage depth of the machine of the tractor electro-hydraulic hitch system according to the different land conditions. A large number of studies have been carried out to improve the working quality of the tractor electro-hydraulic suspension system and reduce energy consumption. A systematic literature review discussing the prevailing state of the tractor electro-hydraulic hitch system in the agriculture sector was presented in this study from three aspects: the tillage depth adjustment method, the tillage depth control algorithm and the key components of the tractor electro-hydraulic hitch system. Conclusions were drawn as follows:

(1) The single-parameter adjustment method does not conform with the high-standard tillage quality requirements of modern precision agriculture. the coupling mechanism between the different adjustment parameters should be paid attention to in further research.
(2) The integration of intelligent control algorithms can effectively improve the quality of work, but the impact of the different soil environments on the control system is not clear, and more field experiment tests will be required.
(3) In terms of hardware, it is necessary to put forward higher design requirements for the key components of the electro-hydraulic hitch system. It is necessary to develop more intelligent control valves and strong anti-interference ability sensing elements.

Therefore, aiming at the key technology of the tractor electro-hydraulic hitch system, the following subsections briefly highlight future emerging trends of the tractor electro-hydraulic hitch system.

6.1. Tillage Depth Adjustment Methods

At present, the tillage depth adjustment methods of the tractor electro-hydraulic hitch system are mainly based on the position adjustment, draft adjustment and mixed draft-position adjustment. There are relatively few studies on slipping, and they are mainly concentrated in single soil conditions and in a single ploughing mode. In the future, the comprehensive adjustment method based on slipping should be explored, so as to improve the applicability under the different operating modes and operating environments.

In addition, in the current multi-parameter adjustment method, the slip rate is more frequently used as a threshold to achieve switch control. Therefore, carrying out research on the coupling mechanism between the multi-parameters based on position, force and slip rate to achieve seamless switching between multi-parameters is also an aspect that most of the current research needs to further consider.

6.2. Tillage Depth Control Algorithm

With the continuous development and maturity of the advanced control theory, in order to realize the optimal tillage depth control of the tractor electro-hydraulic hitch system, more advanced intelligent algorithms should be explored in combination with the characteristics of the tractor electro-hydraulic hitch system. Intelligent algorithms such as the neural network, sliding mode variable structure control can adapt well to the nonlinear tillage depth control system, so as to improve the robustness and accuracy of the control system.

In addition, in the study of the tractor tillage depth control algorithm, researchers have not only been limited to a single algorithmic control, but they also transformed a control mode into combining multiple control algorithms to adapt well to the different control needs.

6.3. Key Components of the Electro-Hydraulic Hitch System

While the tillage depth adjustment method and the tillage depth control algorithm are continuously studied, in order to achieve the required control effect, higher design requirements should be put forward for the key components of the electro-hydraulic hitch system. The intellectualization and digitization of the hydraulic control valves are the trend of future development. Through the built-in sensing elements and the application of the electro-hydraulic digital control, the hydraulic system and control technology can be better combined to improve the control performance of the hydraulic control valves.

For the sensing element, further exploration of new functional materials, such as magnetorheological fluid, magnetostriction material, piezoelectric material, etc., in order to achieve new characteristics and improve the reliability of the sensing element, so as to adapt well to the harsh working conditions, is necessary. In addition, with the development of high-tech, such as autonomous driving and positioning navigation, the research on the multi-sensor fusion technology should be committed and combine with intelligent control algorithms to achieve precision operations.

Author Contributions: Conceptualization, X.S. and Z.L.; writing—original draft preparation, X.S.; writing—review and editing, X.S., Y.S., C.J., Z.C. and J.Q.; English language and style, Y.L. and C.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Key Research and Development Plan of China (Grant No. 2016YFD0701103) and Postgraduate Research and Practice Innovation Program of Jiangsu Province, China (Grant No. KYCX22_0716).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank all teachers and students for their invaluable support.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kiropoulos, K.; Bibi, S.; Vakouftsi, F.; Pantzios, V. Precision agriculture investment return calculation tool. In Proceedings of the 17th International Conference on Distributed Computing in Sensor Systems (DCOSS), Pafos, Cyprus, 14–16 July 2021; IEEE: Electr Network, 2021; pp. 267–271.
2. Gyarmati, G.; Mizik, T. *The Present and Future of the Precision Agriculture, 2–4 June 2020*; IEEE: Budapest, Hungary, 2020; pp 593–596.
3. Yang, X.; Shu, L.; Chen, J.N.; Ferrag, M.A.; Wu, J.; Nurellari, E.; Huang, K. A Survey on Smart Agriculture: Development Modes, Technologies, and Security and Privacy Challenges. *IEEE-CAA J. Autom. Sin.* **2021**, *8*, 273–302. [CrossRef]
4. Bolfe, E.L.; Jorge, L.A.d.C.; Sanches, I.D.A.; Junior, A.L.; Costa, C.C.d.; Victoria, D.d.C.; Inamasu, R.Y.; Greog, C.R.; Ferreira, V.R.; Ramirez, A.R. Precision and digital agriculture: Adoption of technologies and perception of brazilian farmers. *Agriculture* **2020**, *10*, 653. [CrossRef]
5. Anche, G.M.; Devika, K.B.; Subramanian, S.C. Robust Pitching Disturbance Force Attenuation for Tractor Considering Func-tional Constraints. *IEEE Access* **2020**, *8*, 86419–86432. [CrossRef]
6. Shen, W.; Wang, J.H.; Huang, H.L.; He, J.Y. Fuzzy sliding mode control with state estimation for velocity control system of hydraulic cylinder using a new hydraulic transformer. *Eur. J. Control* **2019**, *48*, 104–114. [CrossRef]
7. Sunusi, I.I.; Zhou, J.; Wang, Z.Z.; Sun, C.Y.; Ibrahim, I.E.; Opiyo, S.; Korohou, T.; Soomro, S.A.; Sale, N.A.; Olanrewaju, T.O. Intelligent tractors: Review of online traction control process. *Comput. Electron. Agric.* **2020**, *170*, 105176. [CrossRef]
8. Aravind, K.R.; Raja, P.; Manuel, P.R. Task-based agricultural mobile robots in arable farming: A review. *Span. J. Agric. Res.* **2017**, *15*, e02R01. [CrossRef]
9. Mamkagh, A.M. Effect of soil moisture, tillage speed, depth, ballast weight and, used implement on wheel slippage of the tractor: A review. *Asian J. Adv. Agric. Res.* **2019**, *9*, 1–7. [CrossRef]

10. Mamkagh, A.M. Effect of tillage speed, depth, ballast weight and tire inflation pressure on the fuel consumption of the agricultural tractor: A review. *J. Eng. Res. Rep.* **2018**, *3*, 1–7. [CrossRef]
11. Benkovic, R.; Sumanovac, L.; Jug, D.; Jug, I.; Japundzic-Palenkic, B.; Mirosavljevic, K.; Popijac, M.; Benkovic-Lacic, T. Influence of Aggregated Tillage Implements on Fuel Consumption and Wheel Slippage. *Teh. Vjesn. Tech. Gaz.* **2021**, *28*, 956–962.
12. Mamkagh, A.M. Review of fuel consumption, draft force and ground speed measurements of the agricultural tractor during tillage operations. *Asian J. Adv. Res. Rep.* **2019**, *3*, 1–9. [CrossRef]
13. Singha, P.S.; Kumar, A.; Sarkar, S.; Baishya, S.; Kumar, P. Development of Electro-Hydraulic Hitch Control System through Lower Link Draft Sensing of a Tractor. *J. Sci. Ind. Res.* **2022**, *81*, 384–392.
14. Xu, J.K.; Li, R.C.; Li, Y.C.; Zhang, Y.S.; Sun, H.L.; Ding, X.K.; Ma, Y. Research on Variable-Universe Fuzzy Control Technology of an Electro-Hydraulic Hitch System. *Processes* **2021**, *9*, 1920. [CrossRef]
15. Wang, L.; Wang, Y.; Dai, D.; Wang, X.; Wang, S.M. Review of electro-hydraulic hitch system control method of automated tractors. *Int. J. Agric. Biol. Eng.* **2021**, *14*, 1–11. [CrossRef]
16. Xiong, L.; Sun, S.L.; Xiao, M.T. Agricultural machinery automation and intelligent research and application. *IOP Conf. Ser. Mater. Sci. Eng.* **2018**, *452*, 042077. [CrossRef]
17. Choudhary, R.; Rajarathnam, M.; Alekya, M.; Prithiv, H.K.; Selva, K.S. Agriculture automation system. *J. Phys. Conf. Ser.* **2020**, *1706*, 012089. [CrossRef]
18. Kovacev, I.; Kosutic, S.; Jejcic, V.; Copec, K.; Pliestic, S. Impact of electronic-hydraulic hitch control on rational exploitation of tractor in ploughing. *Strojarstvo* **2008**, *50*, 287–294.
19. Du, Q.L.; Chen, X.H. Design on control system for electro-hydraulic hitch equipment of tractor. *Adv. Mater. Res.* **2014**, *945–949*, 1513–1516. [CrossRef]
20. Olson, D.J.; Cornell, C.R. Simulation of an electrohydraulic hitch control system on an agricultural tractor. *SAE Trans.* **1987**, *96*, 1253–1258. [CrossRef]
21. Li, W.Z.; Xu, Q.C. *Automobile and Tractor*; China Agricultural Press: Beijing, China, 2008; pp. 149–150.
22. Hobbs, J.; Hesse, H. Electronic/hydraulic hitch control for agricultural tractors. *SAE Trans.* **1980**, *89*, 3211–3219. [CrossRef]
23. Xu, T.W. Research and Development of Electronically Controlled Hydraulic System for Medium and Small Tractor Suspension. Master's Thesis, Qingdao Agricultural University, Qingdao, China, 2016.
24. Han, C.H.; Gao, X.H. CAN bus technology and its application. *Manuf. Autom.* **2010**, *32*, 146–149.
25. Scarlett, J.A. Integration of tractor engine, transmission and implement depth controls (Part2, Control Systems). *J. Agric. Eng. Res.* **1993**, *54*, 89–112. [CrossRef]
26. Dwyer, M. The effect of draught control response on the performance of agricultural tractors. *J. Agric. Eng. Res.* **1969**, *14*, 295–312. [CrossRef]
27. Jerzy, Z.; Zbigniew, Z. A functional model of a tractor working with mounted tools. *J. Inn. Mong. Polytech. Univ.* **2003**, *22*, 93–100.
28. Kannakara, S.; Kushwaha, R.L.; Lague, C. Numerical modeling of soil stress and pressure distribution on a flat tillage tool using computational fluid dynamics. *Biosyst. Eng.* **2007**, *97*, 407–414.
29. Bosch Rexroth Electronic-Hydraulic Hitch Control. Available online: https://dc-boschrexroth-cn.resource.bosch.com/media/cn/product/product_groups_1/mobile/mobile_systems/ehc_user_menu.pdf (accessed on 20 August 2022).
30. Walvoil Hitch Control System. Available online: https://www.walvoil.com/allegati/catalogo/D1WWCB06_ENG.pdf (accessed on 20 August 2022).
31. System Description-Hitch Control. Available online: https://assets.danfoss.com/documents/150036/AB152886482484en-000204.pdf (accessed on 20 August 2022).
32. Zhan, K.; Zhang, L.Y.; Qin, W.Q. The simulation study of tractor-hanging farm implements tillage unit on microcomputer. *J. Jilin Univ. Eng. Technol. Ed.* **1990**, *04*, 81–88.
33. Fang, C.L.; Wu, J.H. Theoretical and experimental study on electrohydraulic control of tractor suspension system. *Trans. Chin. Soc. Agric. Mach.* **1994**, *03*, 6–11.
34. Xie, B. Study on Electrohydraulic Control Technology of Suspension System of Tractor Farm Tool Simulation Operation Unit. Master's Thesis, China Agricultural University, Beijing, China, 2000.
35. Xie, B.; Mao, E.R.; Tan, Y. Development of tractor electrohydraulic suspension system controller based on CAN bus. *Mach. Tool Hydraul.* **2006**, *08*, 185–187.
36. Chen, M.J.; Lu, Z.X.; Yuan, Y.Y.; Wang, Q.M. Design of the position-adjust controller for electro-hydraulic hitch system of tractor. *Mach. Electron.* **2008**, *11*, 19–22.
37. Zhan, C. Research on the Tractor Electric-Hydraulic Hitch Congtrol System Based on CAN Bus. Master's Thesis, Nanjing Agricultural University, Nanjing, China, 2008.
38. Lee, J.; Yamazaki, M.; Oida, A.; Nakashima, H.; Shimizu, H. Electro-hydraulic tillage depth control system for rotary implements mounted on agricultural tractor design and response experiments of control system. *J. Terramech.* **1998**, *35*, 229–238. [CrossRef]
39. Lee, J.; Yamazaki, M.; Oida, A.; Nakashima, H.; Shimizu, H. Field performance of proposed foresight tillage depth control system for rotary implements mounted on an agricultural tractor. *J. Terramech.* **2000**, *37*, 99–111. [CrossRef]
40. Xia, J.F.; Li, D.; Liu, G.Y.; Cheng, J.; Zhen, K.; Luo, C.M. Design and test of an electro-hydraulic monitoring device for hitch tillage depth based on measurement of tractor pitch angle. *Trans. Chin. Soc. Agric. Mach.* **2021**, *52*, 386–395.

41. Hao, X.Y.; Wang, Y.L.; Xu, T.W.; Li, Z.M.; Zhang, J.; Geng, C. Modeling and simulation of tractor electronically controlled hydraulic suspension system based on AMESim. *J. Qingdao Univ. Eng. Technol. Ed.* **2018**, *33*, 125–129.
42. Cheng, M.J. Research on Resistance-adjustment for Tractor Electro-hydraulic Hitch System Based on the Fuzzy Algorithm. Master's Thesis, Nanjing Agricultural University, Nanjing, China, 2009.
43. Wang, Q.M. The Research and Design of Electronic Hydraulic Control Technology of Hitch Control Unit for the Tractor. Master's Thesis, Nanjing Agricultural University, Nanjing, China, 2008.
44. Xu, H.; Lu, Z.X.; Song, Y.D. Force-position Adjustment Design of Tractor Hitch System Based on DSP. *Appl. Mech. Mater.* **2014**, *462–463*, 483–486. [CrossRef]
45. Zhang, B.; Zhou, J. Research on prediction of traction resistance of tractor farming based on fuzzy neural network. *J. Gansu Agric. Univ.* **2020**, *55*, 213–220+228.
46. Shang, G.G.; Peng, H.J.; Xia, Y. Study on auto-control method and simulation for tractor depth fuzzy control. *Res. Agric. Mod.* **2014**, *35*, 825–829.
47. Zhao, J.J.; Zhu, Z.X.; Song, Z.H.; Zhou, R.J.; Wang, R.P.; Mao, E.R. Design of electro-hydraulic suspension proportional controller for heavy tractor. *Trans. Chin. Soc. Agric. Mach.* **2014**, *45* (Suppl. S1), 10–16.
48. Xu, H.; Lu, Z.X.; Song, Y.D. Study on force-position regulation of tractor electro-hydraulic hitch system. *Acta. Agric. Zhejiangensis* **2013**, *25*, 879–883.
49. Guo, B. Research on Force-position Combined Control for Tractor Electronically Controlled Hydraulic Hitch System. Master's Thesis, Nanjing Agricultural University, Nanjing, China, 2013.
50. Li, M.S. Research on the Dynamic Performance of Electro-hydraulic Hitch System in Big-Power Tractor. Ph.D. Thesis, China Agricultural University, Beijing, China, 2013.
51. Wang, S.Y.; Liu, Z.; Li, R.C.; Xu, J.K.; Liu, Y.J. Variable weight force-position mixed control of high-power tractor based on soil specific resistance. *Trans. Chin. Soc. Agric. Mach.* **2018**, *49*, 351–357.
52. Ma, Y. Research on Tillage Depth Control Technology of Heavy Tractor Based on Variable Universe Fuzzy PID. Master's Thesis, Shandong University of Science and Technology, Qingdao, China, 2019.
53. Gao, L.L. Study of Electronic Control Technology for Tractor's Hydraulic Hitch System. Master's Thesis, Jiangsu University, Jiangsu, China, 2014.
54. Mu, C.P. Research on Control Technology of Tillage Depth of Electro-Hydraulic Suspension System of Large Tractor. Master's Thesis, Shandong University of Science and Technology, Qingdao, China, 2020.
55. Bai, X.F.; Lu, Z.X.; Chang, J.X.; Li, H.; Zhou, W.W. Fuzzy control algorithm simulation of automatic control of tilling depth for tractor based on slip rate. *Trans. Chin. Soc. Agric. Mach.* **2012**, *43* (Suppl. S1), 6–10.
56. Yu, F.; Lin, Y. *Vehicle System Dynamics*; China Machine Press: Beijing, China, 2016; pp. 42–46.
57. Li, C.J. Research on electro-hydraulic tillage depth control system based on PID control. Master's Thesis, Southwest University, Chongqing, China, 2017.
58. Shen, Z.F. Modeling and Simulation Analysis of Electronically Controlled Hydraulic Suspension System of Tractor. Master's Thesis, Jiangsu University, Zhenjiang, China, 2010.
59. Wang, Z.Y. Dynamic Characteristics Analysis of Tractor Electronically Controlled Hydraulic Suspension System. Master's Thesis, Jiangsu University, Zhenjiang, China, 2012.
60. Zhu, S.H.; Zhang, C. Study on PID control simulation of tractor electro-hydraulic hitch system. *Mach. Des. Manuf. Eng.* **2008**, *21*, 49–53.
61. Li, D.; Ye, J.; Li, M.S.; Li, C.J.; Xu, H.G. Research on tillage depth regulation system based on integral-separated PID control. *J. Southwest-China Norm. Univ. Nat. Sci. Ed.* **2018**, *43*, 121–127.
62. Zhou, M.K.; Xia, J.F. Development of a depth control system based on variable-gain single-neuron PID for rotary burying of stubbles. *Agriculture* **2022**, *12*, 30. [CrossRef]
63. Zadeh, L.A. Fuzzy sets. *Inf. Control* **1965**, *8*, 338–353. [CrossRef]
64. Xie, L.Y. Research on Plowing Depth Automatic Control for High-Power Tractor Electro-Hydraulic Hitch System. Master's Thesis, Jiangsu University, Zhenjiang, China, 2016.
65. Pang, C.L.; Zong, B.H.; Er, Z.M. Fuzzy integrated control model and simulation test of tractor working unit. *Trans. CSAE* **2003**, *4*, 111–113.
66. Lu, Z.X.; Guo, B.; Gao, Q. Fuzzy automatic control method and experimental study of tractor tillage depth. *Trans. CSAE* **2013**, *29*, 23–29.
67. Soylu, S.; Arman, K. Fuzzy logic based automatic slip control system for agricultural tractors. *J. Terramech.* **2021**, *95*, 25–32. [CrossRef]
68. Han, J.Y.; Xia, C.G.; Shang, G.G.; Gao, X. In-field experiment of electro-hydraulic tillage depth draft-position mixed control on tractor. *IOP Conf. Ser. Mater. Sci. Eng.* **2017**, *274*, 012028. [CrossRef]
69. Tan, Y. Study on Performance of Hydraulic Suspension and Loading System of Tractor. Master's Thesis, China Agricultural University, Beijing, China, 2004.
70. Gao, X.; Sun, C.W.; Shi, J.Z.; Wang, Q. Research of fuzzy control method for electronic hydraulic hitch of tractor. *Tractor Farm Transp.* **2008**, *35*, 12–14.

71. Shafaei, S.M.; Loghavi, M.; Kamgar, S. A practical effort to equip tractor-implement with fuzzy depth and draft control system. *Eng. Agri. Environ. Food.* **2019**, *12*, 191–203. [CrossRef]
72. Li, M.S.; Zhao, J.J.; Zhu, Z.X.; Xie, B.; Chi, R.J.; Mao, E.R. Fuzzy PID adaptive control method for tractor electro-hydraulic suspension system. *Trans. Chin. Soc. Agric. Mach.* **2013**, *44* (Suppl. S2), 295–300.
73. Wang, P.Y. Study on the Technology of Adjusting the Plough Depth of Modern Agricultural Tractor Based on Variable Universe Fuzzy Control. Master's Thesis, Shandong Agricultural University, Qingdao, China, 2020.
74. Zhang, S.; Wu, Z.B.; Chen, J.; Li, Z.; Zhu, Z.X.; Song, Z.H.; Mao, E.R. Control method of driving wheel slip rate of high-power tractor for ploughing operation. *Trans. CSAE* **2020**, *36*, 47–55.
75. Moradinejad, N. Electronic hitch control valve for Massey Ferguson 285 tractor. *AMA-Agr. Mech. Asia Af.* **2018**, *49*, 50–56.
76. Zhang, S. Study on slip rate control of heavy tractor for ploughing based on sliding mode variable structure control. Ph.D. Thesis, China Agricultural University, Beijing, China, 2018.
77. Liu, C.Q.; Hua, B.; Du, Y.F.; Li, Z.; Zhu, Z.X.; Mao, E.R. Dynamic pressure feedback correction method for tractor electro hydraulic hitch. *Trans. Chin. Soc. Agric. Mach.* **2020**, *51* (Suppl. S1), 1–9.
78. Zhao, H.P.; Zhou, J.J.; Bao, Q.Q.; Ma, H.C. Characteristic analysis of intelligent reversing valve based on high-speed on-off valve. *Acta Armamentarii.* **2022**. [CrossRef]
79. Li, M.S.; Zhu, Z.X.; Mao, E.R.; Song, Z.H.; Xie, B.; Li, C.L. Design of proportional raise valve in electro-hydraulic lifting mechanism of big-power tractor. *Trans. Chin. Soc. Agric. Mach.* **2012**, *43*, 31–35+89.
80. Zhao, J.J.; Zhu, Z.X.; Song, Z.H.; Mao, E.R.; Liu, S.R.; Liu, D.L. Simulation and test of multi-way directional valve for heavy tractor electro-hydraulic hoist. *Trans. Chin. Soc. Agric. Mach.* **2014**, *45* (Suppl. S1), 1–9.
81. Hua, B.; Zhao, J.J.; Liu, C.Q.; Du, Y.F.; Mao, E.R.; Song, Z.H. Performance simulation and test of plug-in proportional raising valve of electro-hydraulic hitch for heavy tractor. *Trans. CSAE* **2019**, *35*, 109–117.
82. Adamchuk, V.I.; Hummel, J.W.; Morgan, M.T.; Upadhyaya, S.K. On-the-go soil sensors for precision agriculture. *Comput. Electron. Agric.* **2004**, *44*, 71–91. [CrossRef]
83. Li, Z.X. Research and design of operating depth measurement apparatus for farm implement. *Trans. Chin. Soc. Agric. Mach.* **2000**, *31*, 88–91.
84. Mouazen, A.M.; Anthonis, J.; Saeys, W.; Ramon, H. An automatic depth control system for online measurement of spatial variation in soil compaction, Part 1: Sensor design for measurement of frame height variation from soil surface. *Biosyst. Eng.* **2004**, *89*, 139–150. [CrossRef]
85. MacQueene, J.; Schwarz, P.; Nielsen, B. Development of the electronic draft control system for the ford New Holland 8210 tractor. *SAE Trans.* **1990**, *99*, 327–339.
86. Chen, G.; Zhang, B.; Liu, P.; Ding, H. An adaptive analog circuit for LVDT's nanometer measurement without losing sensitivity and range. *IEEE Sens. J.* **2015**, *15*, 2248–2254. [CrossRef]
87. Cai, L.F. Research on the Plowing Depth Automatic Control of Tractor Hydraulic System Based on Electronic Control. Master's Thesis, Jilin University, Changchun, China, 2016.
88. Chethan, C.R.; Tewari, V.K.; Nare, B.; Kumar, S.P. Transducers for measurement of draft and torque of tractor-implement system—A review. *Agric. Mech. Asia Afr. Lat. Am.* **2018**, *49*, 81–87.
89. Zhang, L.Y.; Zheng, X.; Qin, C.M.; He, X.C. Performance test and analysis of super-deep plow. *J. Gansu Agric. Univ.* **2016**, *51*, 156–160.
90. Bentaher, H.; Hamza, E.; Kantchev, G.; Maalej, A.; Arnold, W. Three-point hitch-mechanism instrumentation for tillage power optimization. *Biosyst. Eng.* **2008**, *100*, 24–30. [CrossRef]
91. Kumar, A.A.; Tewari, V.K.; Nare, B. Embedded digital draft force and wheel slip indicator for tillage research. *Comput. Electron. Agric.* **2016**, *127*, 38–49. [CrossRef]
92. Raul, A.K.; Raheman, H.; Pansare, M.S.; Machavaram, R. Predicting the draught requirement of tillage implements in sandy clay loam soil using an artificial neural network. *Biosyst. Eng.* **2009**, *104*, 476–485. [CrossRef]
93. Bhondave, B.; Ganesan, T.; Varma, N.; Renu, R.; Sabarinath, N. Design and development of electro hydraulics hitch control for agricultural tractor. *SAE Int. J. Commer. Veh.* **2017**, *10*, 405–410. [CrossRef]
94. Gao, X.; Wang, Z.Y.; Pan, D.Y. Resistance regulation characteristic analysis of tractor rear hitch mounted hanging plough in multi-operative modes. *J. Anhui Agric. Sci.* **2012**, *40*, 14132–14135.
95. Singh, C.D.; Singh, R.C. Computerized instrumentation system for monitoring the tractor performance in the field. *J. Terramech.* **2011**, *48*, 333–338. [CrossRef]
96. Li, M.S.; Chi, R.J.; Mao, E.R.; Zhang, J.Y.; Liu, Y. Design of draft sensor in big-power tractor raiser based on magnetostriction. *Trans. Chin. Soc. Agric. Mach.* **2013**, *44*, 8–12+32.
97. Li, R.C.; Guo, K.; Yang, J.R.; Xu, J.K.; Chi, Y.R. Magnetic circuit design and simulation of draft sensor in electro-hydraulic lifting mechanism of high-power tractor. *Trans. Chin. Soc. Agric. Mach.* **2017**, *48*, 358–367.
98. Kheiralla, A.F.; Yahya, A.; Bardae, M.Z.; Ishak, W. Design and development of a three-point auto hitch dynamometer for an agricultural tractor. *ASEAN J. Sci. Technol. Dev.* **2003**, *20*, 271–288. [CrossRef]
99. Al-Jalil, H.F.; Khdair, A.; Mukahal, W. Design and performance of an adjustable three-point hitch dynamometer. *Soil Tillage Res.* **2001**, *62*, 153–156. [CrossRef]