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APPLICATION OF LOAD CELLS IN PRECISION AGRICULTURAL EQUIPMENT

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Abstract: Sensors are one of the key technologies to improve the industrialization level of precision agriculture in China. In the entire precision agriculture production cycle, load sensors have potential application areas in every link. This article discusses the application of load sensors in four different stages of precision agriculture implementation: land preparation, precision sowing, crop management, and precision harvesting. The current application and research status of precision agricultural equipment is summarized. On this basis, three main key issues that need to be solved urgently in the practical application of current weighing sensors in precision agriculture are further analyzed: reliability, stability and dynamic measurement accuracy. Finally, the key common technologies involved in solving these problems, including sensitive mechanisms, manufacturing processes and measurement technologies, are further elaborated.
Keywords: Weighing sensor; Load cell; Dynamic weighing; Precision agriculture; Smart agricultural equipment

1 APPLICATIONS IN THE FIELD OF PRECISION AGRICULTURE

A sensor is a device or device that can sense what is being measured and convert it into a usable output signal according to certain rules [1]. The load cell is one of the sensors that measures the mass or force condition of an object. Among them, the load cell based on the principle of resistance strain occupies a dominant position due to its advantages of simple structure, low cost and high accuracy. The resistance strain gauge load cell (referred to as the load cell) is mainly composed of an elastic element, a resistance strain gauge attached to the elastic element, and a compensation resistor. The resistance strain gauge and various compensation resistors are connected to form a Wheatstone bridge, which will be Changes in measured physical quantities are converted into changes in electrical signals through the bridge ratio [2].
As the technical foundation and core component of electronic weighing technology and electronic weighing instrument products, load cells have been widely used in the production and circulation of many industries. In recent years, with the rapid development of emerging industries such as the Internet of Things, smart logistics, and smart agriculture, load sensors have also seen related applications in some new fields. Precision agriculture is one of the fields with broad application prospects. Precision agriculture, also known as precision agriculture or precise agriculture, is a new trend in agricultural development in the world today and the prototype of future agriculture. In the entire precision agricultural production cycle, load cells have potential application markets in every link, such as tractor traction measurement, precision sowing, variable fertilization and spraying, crop yield monitoring, and bale weight monitoring statistics. Etc., relevant application research based on weighing sensors has appeared. According to an assessment by Honeywell in the United States in 2013: In the next 10 years, in the field of grain harvest management technology alone, the development of wireless agricultural sensor systems will drive an investment of approximately US$86 billion. It can be seen that load sensors As one of the key components in grain yield monitoring, its market prospect is bound to be very broad.
This article mainly introduces the current research status of domestic and foreign load sensor technology in the field of precision agriculture, analyzes some of the main technical problems existing in the industrialization of load sensors in the field of domestic precision agriculture, and finally provides some analysis of countermeasures to solve these problems.

1.1 Land Preparation

Land finishing is an important part of precision agriculture, which is mainly performed by tractors pulling agricultural machinery. Agricultural tools are controlled through the electro-hydraulic suspension system installed on the tractor. The basic control methods are force control, position control and force-position comprehensive control. Weighing sensors are used to measure the force conditions of agricultural machinery suspensions and feed them back to the control system for decision-making. However, the agricultural machinery suspension system is a dynamic nonlinear inertial system during operation, and its comprehensive electronic control has not been satisfactory. The main reason is that the stability of the control method and sensor performance cannot adapt to the complex operating environment [3]. Literature [4] designed a Dynamometer (that is, a load cell or a combination of several load cells) with adjustable width and height dimensions to adapt to different installation conditions of agricultural tools and save costs. Literature [5] designed a Dynamometer with a measuring range of 180 kN based on the DEOR structure, which can measure horizontal and vertical forces at the same time. The mutual interference between the two is low and the linearity index of the sensor is very good. In order to improve operating efficiency and reduce energy consumption, literature [6] designed a new three-point suspension Dynamometer for John Deere's 3140 tractor. Compared with other similar Dynamometers, its measurement accuracy is not sensitive to changes in suspension points, and it is manufactured The cost is relatively lower. With the continuous development of digital sensors, literature [7] developed an embedded

digital traction force measurement device and combined it with other sensor data to analyze the conditions during the farming process.
In addition, literature [8] designed a weighing sensor installed on agricultural tools to measure soil resistance, and then used it together with other sensors to measure soil bulk density in real time. Literature [9] studied a multi-sensor platform including load cells to generate soil density distribution maps for the formulation of farming plans for precision agriculture.
Abroad, load cells have been commercially used in tractor suspension systems, and their research directions have begun to shift toward the digitization and intelligence of sensors, expanding the application scope of load cells, and combining multi-sensor data fusion to improve the efficiency and efficiency of agricultural machinery operations. quality.
In China, currently tractors are still mainly characterized by simple structures and mid- to low-end technical performance. Relevant research is more focused on the control system of the tractor suspension, and there is relatively little research on load cells. For example, Han Jiangyi and others from Jiangsu University [10] developed a pin-type sensor in order to measure the traction force of a high-horsepower tractor. They mainly simulated the elastomer design of the sensor, but other important technologies such as the packaging of the load cell have not yet been developed. Elaborate.

1.2 Precise Sowing

The seeder is the main means to achieve precise sowing. Its performance directly affects the quality of sowing, the growth status and yield of crops. A more intuitive application is to install a weighing sensor between the seed hopper and the frame of the seeder to monitor it at any time. The internal conditions of the seed hopper, combined with the speed sensor, etc. can realize the statistics of the unit seeding rate. For example, US patent US9539927 B2 [11], WO2012/170548 A2 [12], etc. all describe similar solution structures and measurement methods based on weighing sensors. They all use weighing sensors with a similar Weigh bar structure. In China, Wang Suzhen et al. [13] designed a weighing sensor on the seed metering device of the drill, and the tractor was equipped with a rotational speed sensor. Then, they collected the reading changes of the weighing sensor and rotational speed sensor, calculated the unit seeding amount, and It can be recalibrated for different sowing objects to adapt to the precise sowing of various crops, but the technical characteristics of the weighing sensor are not explained. The air-suction vibrating seed metering device puts the seeds in a "boiling" state through vibration and relies on airflow to move the seeds Adsorption, and then seeding with positive air flow, has the advantages of high precision and good versatility, and is an important development direction of precision seed metering devices. In order to ensure that the seeds in the vibrating plate are in a better "boiling" state, it is necessary to control the number of seeds in the seed plate. In recent years, relevant personnel [14] studied the monitoring of seeds in the vibrating plate through a double-hole parallel beam load cell. Seed distribution, quantitative seeding, and improved sowing quality.
In addition, sowing depth also has a significant impact on crop yield. Literature [15] studied the depth active control system during seed sowing. A compact cylindrical load cell was installed on the spring of the seeding mechanism to measure the force of the seeding mechanism inserted into the soil and combine it with the displacement sensor data. Feedback to the seeding control system.
Finally, suppression is also an important part of precision sowing operations and has a great impact on seed germination, emergence and final yield. For different soil, water content and crop types, the suppression intensity should be different. There are many studies on this abroad, and there are more than 200 species in the United States alone [16]. In China, Wang Jingli et al. [16] designed a variable-force seedling belt suppressor, which uses the gravity of the suppressing wheel, the bracket and the pressure of the hydraulic cylinder to act on the ground where the suppressing wheel is in contact. A pair of weighing sensors are installed in one wheel to measure The pressure between the wheel and the ground. Changing the stroke of the hydraulic cylinder can change the force acting on the wheel shaft, thereby changing the pressure of the compaction wheel on the soil of the seed bed.

1.3 Precision Crop Management

Precision crop management refers to various management measures for crop growth from crop sowing to harvesting, including the management of water, fertilizer, and medicine. The traditional application method of chemical fertilizers and pesticides has low utilization rate, which has caused serious ecological environment and agricultural pollution problems [17]. Variable fertilization and spraying technology in precision agriculture can effectively improve the utilization rate of fertilizers and pesticides, save costs, and increase yields. Literature [18] designed a dynamic weighing system. Three load cells were installed on the suspension of the fertilizer spreader. One 50 kN shear beam sensor was used as the main weighing sensor, and the other two parallel beam sensors were used. They are 20 and 500 N respectively, which are used as reference sensors to compensate for vibration and other signals. During the field test of this system, the weighing system measured in the range of 6 to 20 kN, the standard deviation did not exceed 20 N, and the response time was within 1 s.
Soil testing and formulated fertilization is an advanced agricultural technology promoted by the United Nations around the world, and it is also an important technology in precision agriculture. Literature [19] uses the weighing method to feedback fertilizer flow information, uses four 400 kg weighing sensors to support the fertilizer box, monitors the changes in fertilizer quality in the fertilizer box, and adjusts the amount of fertilizer according to the current vehicle

speed. The test shows that the operation The accuracy has a lot to do with the accuracy of fertilization flow (obtained by the load sensor) and vehicle speed detection, which needs further verification and improvement. Literature [20] uses the same weighing method, except that each fertilizer box uses 3 weighing sensors, which reduces the cost, and uses a fuzzy control algorithm to obtain the effective sensor data of the weighing sensors of each raw material box, and then realizes intelligent variable allocation. Fat. During the test phase, the maximum weighing error of the system was 1.2%.

In terms of variable spraying, in order to solve the problem of poor control stability caused by the shaking of the spray tank of the boom sprayer, Zhang Andong et al. [21] designed a special three-way force sensor to monitor the vibration caused by the shaking of the spray tank. Additional force. The sensor is an overall symmetrical structure composed of upper plate, side plate and lower plate. The four side plates are used as strain beams to measure the additional force generated by shaking. Q235 is used as the material of the elastic element of the sensor, which has poor strength and corrosion resistance.

In terms of water-saving irrigation management, literature [22] used parallel beam weighing sensors to develop a convenient and low-cost water consumption measurement method. The test showed that the measurement range was 1.94 to 7.78 dm3 ·s -1. The degree of certainty is 5.7%. Literature [23] established a multi-sensor monitoring platform to guide water-saving irrigation. A 9 t shear beam load sensor is mainly used to monitor the depth of deep plowing, similar to Literature [9].

1.4 Accurate Harvesting

Generating plot yield maps and prescription farming through grain yield measurement is the basis for the application of precision agriculture. The impulse grain flow sensor, which is derived from the traditional weighing load cell, has been widely used in combine harvester production measurement systems due to its simple structure, low cost, and easy installation. Foreign commercial agricultural machinery equipment, such as the flow sensors in the combine harvester yield monitoring systems of Micro Track Company, CASE IH Company and Ag Leader Company, all use impulse-based flow sensors [24].

At present, foreign applied research has shifted from food crops to fruits, vegetables and cash crops. Literature [25-26] studied the yield monitoring system of citrus. They used two completely welded and sealed load cells installed at the end of the vibration conveying system. In order to reduce the influence of vibration, the relationship between the installation position of the load cell and the sensor response characteristics of this welded sealing structure was studied. Under low-speed flow, compared with the actual weight, the average error is 3.56%, and the high-speed flow error is 9.16%. Literature [27] designed an impulse plate yield sensor for peanut yield monitoring, and conducted a comparative test with a photoelectric yield sensor. It was found that the error of the impulse plate yield sensor was about 10%, while the error of the photoelectric type was only 1.54%. They believe that the error of the impulse yield sensor mainly comes from the old walking straw harvester used in the test. Literature [28] used the finite element method to analyze the dynamic characteristics of the weighing system in grape harvest machinery under different weighing conditions, and gave suggestions for improving weighing accuracy.

In addition, due to the zero drift of the sensor in actual use, the literature [29] studied the zero drift compensation algorithm of the small octagonal weighing sensor. After the zero drift was compensated, the relative error of the measurement was reduced from 19% before compensation to 1.5% after compensation.

Domestic research on grain yield measurement has been carried out [30-34] and certain results have been achieved. China Agricultural University developed an impact type grain flow sensing monitoring system earlier in the country, with a measurement error of 2.07% to 5.44%; South China Agricultural University developed a double-plate differential impulse type grain flow sensing monitoring system, which can reduce The impact of small body vibration on the yield measurement accuracy, the relative error of grain flow measurement at 0.5 ~ 2.0 kg · s -1 does not exceed 3%; Jiangsu University developed a load-bearing plate grain flow sensor monitoring system, grain flow When the flow rate is less than 2.0 kg·s -1, the relative error of measurement does not exceed 2%. When the grain flow rate exceeds 2.5 kg·s -1, the relative error of measurement is about 5%. The Chinese Academy of Agricultural Mechanization Sciences developed a weighing system. Type grain flow monitoring system, the measurement error indoors and in the field does not exceed 2% and 3% respectively. In terms of sensor optimization design research, the literature [35-36] studied the structural optimization of the elastic element of the sensor, while the literature [37-38] studied the noise elimination and dynamic compensation of the sensor and achieved certain results.

2 PROBLEMS

Through an overview of the research and application of the above different sub-fields, the research and application status of weighing sensors in precision agriculture can be summarized as follows: First of all, compared with other countries, European and American countries, especially countries represented by the United States, are more advanced in weighing sensors. The application in the field of precision agriculture has achieved certain industrialization results. Among Asian countries, Japan and South Korea are also in a leading position on the road to industrialization research. There are no obvious industrialization cases in my country yet. Secondly, from the perspective of research and application fields, there are currently many applications of load sensor technology in the precision harvesting stage of precision agriculture in my country, and certain results have been achieved, while there are relatively few studies in the stages of land preparation, precision sowing and precision crop management. few. Third, from the perspective of development stage, our country is actually still in the "agricultural application of industrial sensors" stage. In many research experiments, traditional industrial weighing sensors are used. The functions and sensitivity of these sensors There is still a lot of room for improvement in agricultural applications in terms of accuracy and accuracy. However, in the process of agricultural sensor research in my country, product awareness is relatively weak, which causes many problems in applying the research results to production practice, limiting its industrialization in precision agricultural equipment. Finally, combined with the research results of the above-mentioned literature, the article summarizes the disadvantages faced by load sensors in precision agriculture as follows:

First, dynamic measurement accuracy. Dynamic weighing technology has always been a research field of concern to domestic and foreign sensor companies and research institutions, and is also the main consideration in the current application of weighing sensors in precision agriculture. In addition to some interference factors that need to be considered in the traditional dynamic weighing field, there are also Consider that agricultural machinery will inevitably receive impulses from all directions when working and moving, which will cause the load cells installed on the vehicle to feel other interference forces besides gravity, resulting in a reduction in measurement accuracy; at the same time, the ground Unevenness will also cause the load cell to not necessarily remain in the ideal horizontal position during measurement, which will also affect the measurement accuracy. Therefore, the dynamic measurement technology under the working state of agricultural machinery needs to consider more interference factors and is more complex. It is complex and requires in-depth research.

Second, stability. This is a key issue that is easily overlooked in current research. Literature [29] did a simple compensation study on this, but did not conduct an in-depth analysis of the internal mechanism of the output drift. For traditional weighing sensor applications, the imperceptible slow drift of the sensor output data will not have a significant impact on the measurement accuracy in most weighing situations in the past, because it can be cleared through the instrument before each weighing. Eliminate drift errors. However, in weighing situations in agricultural equipment, sensors more often need to perform real-time weighing and measurement for a long time, so the traditional instrument clearing method cannot be used to eliminate drift errors. Another situation that cannot be ignored is that the vehicle will always produce bumps and vibrations when in use, which is equivalent to accelerated aging of the load cell, resulting in accelerated accumulation of measurement errors, which requires the load cell to have higher long-term stability.

Third, reliability. Reliability is a key issue that must be solved when a new technology or product is industrialized. In actual work, vehicle-mounted weighing sensors in agricultural equipment will inevitably encounter bumps and impacts caused by uneven roads, impacts during loading and unloading of materials, vehicle collision impacts, and wind and rain in the wild, etc. This requires that the load cell should have good impact resistance, waterproof and moisture-proof capabilities and a certain working life. In the vehicle industry, parts are generally required to have an expected working life of 10 years, which is much higher than the working life requirements of general electronic scales. Although some relevant domestic research involves the design of weighing sensors, the service life of such sensors in the working environment of agricultural machinery has not been effectively verified, and technologies such as packaging design related to sensor reliability have not been considered in depth.

3 COPING STRATEGIES

Through the above analysis, it is believed that the key to the application of weighing sensors in precision agriculture is to solve the problems of reliability, stability and dynamic measurement accuracy of the weighing sensors. In order to find solutions to the problems, it is necessary to further analyze the key technologies behind these three problems at the sensor technology level.

The technical field of sensors can be divided into four key basic points: sensitive mechanism, functional materials, manufacturing process and measurement technology [39]. Key technologies involved in solving the reliability of weighing sensors include the sensitive mechanism of weighing sensors (such as elasticity). component design and other technologies), functional materials, manufacturing processes (such as sealing processes), etc.; key technologies related to stability include functional materials of load cells, manufacturing processes (such as aging processes), etc.; and key technologies for dynamic measurement accuracy are related to It is related to the sensitive mechanism of the weighing sensor, measurement technology (such as dynamic compensation algorithm, etc.). It can be seen that the three issues of sensor reliability, stability and dynamic measurement accuracy are not isolated. They all involve some common key technologies in the field of weighing sensor technology.

1) Design of elastic components. The elastic element in the load cell that senses the measured physical quantity is a key part that affects the performance and quality of the sensor [40]. The structural designs of elastic elements are diverse, aiming to improve the sensitivity and stability of the measured physical quantities. Through reasonable structural design, the response speed and anti-interference ability of the sensor in the working environment of agricultural machinery can be improved. In this regard, the literature [35-36] have done some research on improving the dynamic characteristics of the sensor, but they did not consider overload and Impact protection issues.

2) Sealing process and aging process. The sealing process is a key technology to ensure the reliability and stability of the sensor. There are two main ways to seal the load cell: sealing with coating materials and sealing with metal welding. Among them, the latter uses a metal diaphragm to completely seal the strain area of the elastic element through a welding process, thus achieving the purpose of completely protecting the internal strain gauge and conversion circuit of the sensor, and has high reliability. Therefore, load cells based on welding seals are very suitable for applications in the

agricultural field. However, there are also some problems with welding sealing technology. Since welding is performed on elastic components, even if laser pulse welding and other processes are used, welding residual stress and deformation will inevitably occur. During subsequent use, the release of residual stress and structural deformation will affect the strain gauge on the elastic element, ultimately causing the output signal of the load cell to change slowly over time. Therefore, the welding process has a significant impact on the long-term stability of the sensor output. Significant impact. At the same time, adding a sealing diaphragm to the sensor will also have an impact on the accuracy of the sensor. Therefore, the sealing diaphragm will generally choose a very thin metal to reduce its additional impact on the elastic element of the sensor. However, the diaphragm is too thin. Welding defects and deformation are prone to occur during welding. Especially for small-scale load cells, after adding a sealing diaphragm, the performance accuracy and stability are often far inferior to the test results before welding, making it particularly difficult to design and manufacture.

The aging treatment of the sensor can reduce the residual stress and improve the stability of the sensor. Relevant companies and scholars have done a lot of research [41]. For welded and sealed load cells, the aging process is generally arranged after the sensor is welded and sealed. At this time, it is also necessary to consider not affecting other parts of the sensor, such as strain gauges and Wheatstone bridge circuits, etc., which limits all Ability to choose the range of processes. Common aging treatment processes include: overload static pressure method, vibration aging method, hot and cold cycle method, etc. However, these methods either have limited effects and cannot completely eliminate residual stress, or the cost is too high to be used on a large scale. In short, there is no simple and effective method so far.

3) Dynamic compensation algorithm. Digital compensation algorithm is the key to improving dynamic measurement accuracy. However, the effectiveness of the digital compensation algorithm depends on the correct establishment of the sensor mathematical model. Previous research often ignored the additional impact of sensor reliability design and stability design on the correct establishment of sensor mathematical models. For example, when using a welded-sealed sensor, it is necessary to consider the impact of the welded-sealed process on the sensor response characteristics. Literature [42] studied the impact of atmospheric pressure on the characteristics of a welded-sealed sensor, and conducted error compensation research; while in In China, there has been no in-depth research on the performance of welded sealed load cells. In addition, in addition to the need to consider the fast response time of sensors in the traditional field of dynamic weighing, for on-board weighing and force measurement of agricultural machinery, it is also necessary to consider the complexity of the actual application environment, such as the forward speed of agricultural machinery, rugged roads and Various factors such as mechanical working vibration affect the sensor test accuracy, so it is necessary to continue to conduct in-depth research on the dynamic digital compensation algorithm of the sensor.

4 CONCLUSION

As modern agricultural equipment continues to develop towards automation and intelligence, load cells will be increasingly used in agricultural production. Due to the complexity of agricultural production operations, higher requirements have been put forward for load cells and technology. Developing vehicle-mounted weighing sensors with fast response speed, strong anti-interference ability, high reliability and high accuracy has become one of the development directions. The development of dynamic digital load cells based on welded seal design is one of the effective ways. At present, due to the lack of research on related basic manufacturing processes and measurement technologies, the stability and accuracy of such sensors are poor, and there are no corresponding mature products in China. Therefore, research in this area has practical application value and will also help domestic sensor company products reach or exceed the international advanced level.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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