Design and test of tilling depth measurement device based on angle sensor

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Abstract. Inter-tillage is one of the most important methods to increase crop yield, reasonable tilling depth can improve crop yield and economic benefits. In the research, an angle sensor-based tilling depth measurement device was designed and its function was tested. The tilling depth measurement device was mainly composed of a supporting palm, an angle sensor, a spring, shaft components, a connection block, a regulating damper and so on, through reasonably designing the geometric structure of the supporting palm in the tilling depth measurement device and combining with the angle sensor, the information of tilling depth was converted into electrical signal, and the linear relationship between tilling depth and electrical signal was obtained. In laboratory test, the calibration and accuracy verification experiments of the tilling depth measurement device were carried out. The correlation coefficient (r) of reference values and measured values using the tilling depth measurement device was 0.9996 with the standard error (SE) of 0.08 cm. In field test, the accuracy of the tilling depth measurement device was also verified with the maximum absolute error of 0.8 cm. The research results showed that the measurement device based on angle sensor had high measurement accuracy, providing a simple and direct tilling depth measurement method.

1. Introduction
Tillage depth is an important parameter to measure the operating performance of farm machinery, reasonable tilling depth can improve crop yield and economic benefits [1, 2]. Traditional manual measurement method of tilling depth has high labor intensity, low efficiency and large measurement error, can’t obtain the tilling depth status in real time. With the applications of electronic, sensor and information technology in the tractor, the traditional manual measurement method of tilling depth has been replaced by various electronic measurement sensors, instruments or devices gradually.

Based on the literature about tilling depth measurement in China and abroad, the existing tilling depth measurement technology mainly includes the use of ultrasonic sensor to measure the tilling depth [3], which is vulnerable to the influences of uneven ground, crop branches and stubble, and such influences are difficult to be removed. The technology also contains the use of contour wheel (land wheel) or copying slip palm to measure the tilling depth [4-7], the contour wheel or the copying slip palm is installed on a plough frame, when the plough falls, the contour wheel or the copying slip palm still keeps contact with the cultivated land. After the plough is deep into the ground, the contour wheel or the copying slip palm is raised relatively, leading to rotation angle changes of the contour wheel or the copying slip palm, at last, the tilling depth was obtained by converting the rotation angle changes,
this method is more practical, but needs to install a set of additional devices. The use of position sensor is also a main technology to automatically measure the tillage depth of agricultural tools [8-11], the tillage depth is calculated by measuring the angle change of the lifting arm of the suspension mechanism, this method is convenient for installation and integration, but relies on the geometric relationship of the suspension mechanism, and the calibration method is complex and tedious.

In the presented research, a tillage depth measurement device was constructed based on angle sensor and a corresponding method of tillage depth measurement was studied, and the measurement precision was tested to verify the feasibility of the device and method.

2. Design of the tillage depth measurement device
The tillage depth measurement device was mainly composed of a supporting palm, an angle sensor, a spring, shaft components, a connection block, a regulating damper, etc., whose three-dimensional structure is shown in figure 1. The measurement device was installed on a tillage machine with a certain horizontal distance from the tillage shovel of the tillage machine, and the supporting palm of the measuring device was in direct contact with the cultivated land surface. When the tillage shovel was deep into the ground, the supporting palm was in direct contact with the cultivated land surface throughout, it was raised relatively, and a certain height difference between the supporting palm and the tillage shovel was produced, through the angle sensor, the measurement device measured this height difference, namely the tillage depth, the schematic of the device in different working positions is shown in figure 2, $H_0$ is the initial position of the supporting palm when it was naturally suspended and in direct contact with the cultivated land surface, $H$ is the working position of the supporting palm, $\Delta H$ is the height difference between the supporting palm and the tillage shovel, namely the tillage depth. By reasonably designing the geometric structure of the supporting palm in the tillage depth measurement device and using the angle sensor, the information of tillage depth was converted into electrical signal, and the linear relationship between tillage depth and electrical signal was obtained.

![Figure 1. The three-dimensional structure of the tillage depth measurement device. (a) Drawing of partial enlargement and (b) Full thumbnail.](image)

The angle sensor converted angle data into electrical signal, the angle data and the electric signal showed a linear relation. The geometric structure of the supporting palm in the tillage depth measurement device was reasonably designed, so that the vertical coordinate of the edge trajectory in contact between the supporting palm and the cultivated land surface had a linear relationship with the rotation angle of the supporting palm, and the rotation angle of the supporting palm was measured by the angle sensor accurately, therefore, the vertical coordinate of the edge trajectory in contact between
the supporting palm and the cultivated land surface had a linear relationship with the electrical signals, and then, there appeared a linear relationship between the electrical signal and the tillage depth of the tillage shovel. The linear regression analysis of the electrical signal and the tillage depth measured by the tillage depth measurement device was carried out, and the linear regression equation was established.

3. Calibration experiment of the tillage depth measurement device

3.1. Experimental materials
In the calibration experiment, the tillage depth measurement device, a lifting platform, a support frame, a ruler, a data collector and a computer were utilized. The lifting platform kept the supporting palm of the tillage depth measurement device at different heights, and the supporting palm was always in contact with the surface of the lifting platform during the experiment. The support frame was used to fix the tillage depth measurement device. The ruler measured the height of the lifting platform. The data collector was connected with the angle sensor of the tillage depth measurement device to obtain the digital voltage signals of the angle sensor in real time and send the digital voltage signal to the computer through wireless communication. The computer received the voltage data sent by the data collector in real time to fit the linear model of tillage depth and voltage.

3.2. Experimental methods
The initial height of the supporting palm when it was naturally suspended was taken as the height datum. In the course of working, the supporting palm was always in contact with the surface of the lifting platform, the lifting range of the lifting platform was 1.0～15.5 cm. When the lifting platform rose or fell with the interval of 0.5 cm, the voltage data of the tillage depth measurement device was recorded accordingly, there were 30 voltage data totally for one way which was repeated for 3 times.

3.3. Data analysis and modeling
Averaged 3 measured voltage values for each height, and regarded the average voltage value as the voltage value of the corresponding height, there were 30 groups of height and voltage values totally. Taking the height value as the tillage depth, the linear fitting of the tillage depth and the electric signal was carried out, and the linear model of the tillage depth and electric signal was established, the relation between the tillage depth and the electric signal was shown in figure 3, the fitting determination
coefficient ($r^2$) was 0.9998 with the standard error (SE) of 0.07 cm. The linear equation of the relationship between the tillage depth and voltage is shown in equation (1),

$$y = -10.911 \cdot x + 20.655$$

where, $y$ represents the tillage depth with the unit of cm. $x$ is the voltage, and the unit is V.

4. Laboratory verification test

4.1. Experimental materials
The experimental materials were the same as the calibration experiment. The difference was that the computer brought the voltage data into the linear model of tillage depth and voltage, output and saved the tillage depth data.

4.2. Experimental method
Took the height of the supporting palm as the height datum when it is naturally suspended, the supporting palm was in contact with the surface of the lifting platform, the lifting range of the lifting platform was $0.5 \sim 12.5$ cm. Once the lifting platform rose or fell, the current height $H_n$ of the lifting platform (the support palm) and the tillage depth data $D_n$ measured by the tillage depth measurement device were recorded, there were 25 groups of depth data, $n$ was equal to 1, 2, 3..., 25.

4.3. Data analysis
Correlation analysis was conducted between the actual height $H_n$ (reference value) of the supporting palm and the tillage depth data $D_n$ (measured value) measured by the tillage depth measurement device, the correlation coefficient ($r$) was 0.9996 with the SE of 0.08 cm. The correlation analysis effect diagram of the reference value and the measured value is shown in figure 4. The experimental results showed that the tillage depth measurement device had high measuring accuracy under static condition.

![Original data and fitting curve](image-url)
Figure 4. The correlation between the measured value and the real value in laboratory verification test.

Figure 5. The correlation between the measured value and the real value in field validation test.

5. Field validation test
In the field condition, the measurement device was installed on the front side of a tillage machine and
driven by a tractor. Totally, 20 measuring points were selected in the test area. Firstly, the tillage depth of each test point was measured with this measurement device as the measured value. Then, the tillage depth of each test point was measured manually as the reference value, a total of 20 groups of measured values and reference values were compared. Correlation analysis was conducted between reference value and measured value, the correlation coefficient \( r \) was 0.9873. The correlation analysis effect diagram of the reference value and the measured value is shown in figure 5. \( x \) means the reference value and \( y \) is the measured value. The experimental results showed that the measurement device had a high measuring accuracy under the field dynamic condition, and the measuring absolute error was no more than 0.8 cm.

6. Conclusion
In this study, a tillage depth measurement device based on angle sensor was designed. By reasonably designing the geometric structure of the supporting palm in the tillage depth measurement device, and using the angle sensor, the information of tillage depth was converted into electric signal, and the relationship between the tillage depth and electric signal was linear. According to the measurement principle analysis and calibration results, the fitting determination coefficient \( r^2 \) was 0.9998 with the standard error \( (SE) \) of 0.07 cm.

Laboratory verification test results showed that there was a high correlation between the measured value and the reference value with the correlation coefficient \( r \) of 0.9996 and the standard error \( (SE) \) of 0.08 cm under static conditions, the tillage depth measurement device had high measurement accuracy. Field verification test results showed that the measuring absolute error of the measurement device was no more than 0.8 cm in dynamic condition, the measurement accuracy was high.

In the working process of the tillage depth measurement device, the supporting palm was in direct contact with the cultivated land surface, which was easy to be worn out in long-term use. Therefore, it was necessary to replace the support palm regularly and calibrate the tillage depth measurement device.

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References
[1] Jia H, Guo M, Yu H, Li Y, Feng X, Zhao J and Qi J 2016 An adaptable tillage depth monitoring system for tillage machine Biosysems. Eng. 151 187-199
[2] Yao S, Teng X and Zhang B 2015 Effects of rice straw incorporation and tillage depth on soil puddlability and mechanical properties during rice growth period Soil. Tillage. Res. 146 125-132
[3] Li Z 2000 Research and design of operating depth measurement apparatus for farm implement Trans. Chin. Soc. Agric. Mach. 3 88-91
[4] Mouazen A M, Anthonis J, Saeys W and Ramon H 2004 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 Biosysems. Eng. 2 139-150
[5] Wu W and Ma R 2007 Design of the automatic control of the plowing depth of the integrated plowing set J. Agric. Mech. Res. 9 77-79
[6] Li L, Li J, Li X, Huang Y and Wang Y 2001 Design researches on tiling depth electron testing system J. Shihezi Univ. Nat. Sci. 3 246-248
[7] Xie B, Mao E and Tan Y 2006 Development of electronic hydraulic hitch controller based on CAN bus Mach. Tool Hydraul. 8 185-187
[8] Lee J, Yamazaki M, Oida A, Nakashima H and Shimizu H 2000 Field performance of proposed foresight tillage depth control system for rotary implements mounted on an agricultural tractor
[9] Bentaher H, Hamza E, Kantchev G, Maalej A and Arnold W 2008 Three-point hitch-mechanism instrumentation for tillage power optimization Biosys. Eng. 1 24-30

[10] Singh C D and Singh R C 2011 Computerized instrumentation system for monitoring the tractor performance in the field J. Terramechanics 5 333-338

[11] Du Q, Xiong X and Wei J 2008 Design and experiment on the control system of electro-hydraulic plow depth of tractor hydraulic hitch mechanism Trans. Chin. Soc. Agric. Mach. 8 62-65