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IMPROVING DEPTH ACCURACY BY USING A REAL-TIME MONITORING SYSTEM FOR TRADITIONAL TILLAGE MACHINERY

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ABSTRACT

Tillage depth has a great influence on soil quality, fuel consumption, and equipment durability in mechanized farming. However, traditional methods often maintain a fixed depth, lacking the ability to adjust in real time. This study proposes a real-time monitoring system that significantly improves the depth measurement accuracy of traditional tillage machinery. The system is equipped with a soil contact wheel combined with an angle sensor, which converts the rotation angle into a depth value based on a geometric relationship. Non-penetrating tests with depths ranging from 10-100 mm show that the Root Mean Square Error (RMSE) ranges from 0.0050-3.2757 mm and the accuracy always exceeds 97.99%, reaching the highest level of 99.77% at 60 mm. The results demonstrate the high reliability and accuracy of the system, laying the foundation for future field tests and automatic control applications.

Keywords: Precision agriculture, tillage machine, tillage depth, monitoring system, adaptive mechanism

INTRODUCTION

Tillage depth is an important technical parameter that directly affects the quality of tillage, fuel consumption and equipment life in mechanised agricultural cultivation (Deng et al. 2025). However, with complex and constantly changing field terrain conditions, maintaining stable plowing depth is still a big challenge, especially for traditional plows that have not integrated automatic monitoring and control systems (Luo et al. 2022). Previous studies on tillage depth monitoring are mainly divided into two groups including non-contact methods using ultrasound, lidar (Martinez-Agirre, Álvarez-Mozos, and Giménez 2016) and contact methods (using displacement sensors, pressure sensors or depth measuring wheels) (Jia et al. 2016). The non-contact method allows remote measurement, but the accuracy is affected by signal conditions and high cost. Meanwhile, the contact method has a simple structure, is easy to integrate with traditional plows, but has limitations in signal stability when moving on rough terrain or when turning (Kim et al. 2020; Zhu et al. 2024).

This study presents a real-time monitoring system for traditional tillage, incorporating an adaptive mechanism with a contact wheel, swing arm, and angle sensor. Furthermore, a caster

wheel combined with a directional spring enables the wheel to remain tangent to the turning radius during curves, reducing both measurement errors and horizontal forces on the swing arm. Additionally, the sensing device was mounted immediately in front of the tiller machine to minimize signal latency and ensure high-accuracy depth detection under real field conditions. The paper presents the system structure, operating principle, and initial experimental results, evaluating the applicability of the system in real-time field plowing depth monitoring.

MATERIALS AND METHODS

The real-time depth monitoring system was configured on a tractor-implement assembly, as depicted in Figure 1. The entire rotary tiller (YANMAR ER214M), including the integrated sensing mechanism, was attached to a tracked agricultural tractor (Yanmar AC-18) via a three-point hitch system. The system was mounted at the front of the tiller to ensure that the acquired data provides an instantaneous reflection of the upcoming terrain. This mechanism consists of a ground-contact wheel affixed to a swing arm. The arm is connected to the frame by a pivot shaft, onto which a potentiometer (TOCOS RV30YN20S B103 10kOhm) is installed to function as an angular sensor. An alignment spring is also integrated to stabilize the wheel's orientation, enabling it to maintain a tangential path relative to the tractor's trajectory during turns.

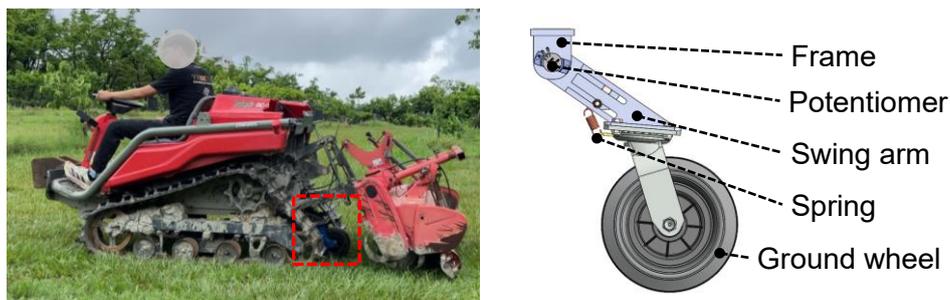


Fig. 1 Configuration of the real-time monitoring system.

The operating principle of the device is illustrated in Figure 2. As the tractor moves at a velocity V , variations in the ground surface elevation (ΔD) cause the wheel to displace vertically. This motion makes the swing arm pivot, changing its angle from a reference value φ_0 to a new value φ_1 . This angular displacement is registered by the potentiometer and converted into a corresponding analog voltage signal. The signal is subsequently digitized by a 12-bit Analog-to-Digital Converter (ADC) at a sampling frequency of 500 Hz. The filter's cutoff frequency was set to 10 Hz, effectively removing high-frequency disturbances from the signal. The filtered data is then utilized in a geometric model to accurately compute the tillage depth (ΔD) based on known mechanical parameters, such as the arm length (L) and wheel radius (R).

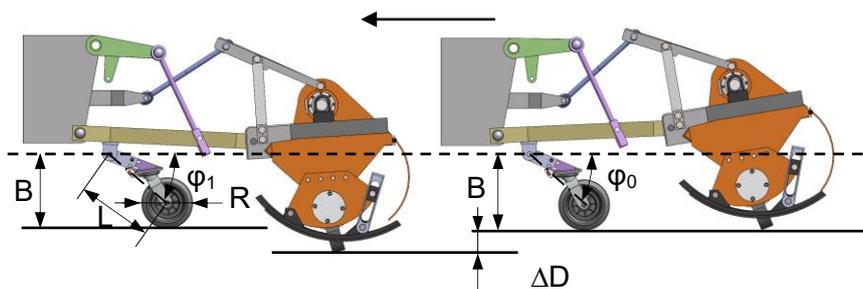


Fig. 2 Working principle of the detection device.

RESULTS & DISCUSSION

The performance of the angle sensor was evaluated in multiple stages. The sensor's calibration process indicated a strong linear relationship between its readings and the actual reference angle, achieving a coefficient of determination $R^2 = 0.99$, which demonstrates high accuracy in the signal conversion.

Table 1 summarizes the detailed results of a non-penetrating test method. The table shows low RMSE (Root Mean Square Error) values and high accuracy (%) at all target depths, with most accuracy values above 98%. This confirms that the system is capable of measuring depth reliably and accurately, even in controlled, non-penetrating environments. These results confirm that the proposed monitoring system provides reliable and high-accuracy depth measurements, meeting the precision requirements for real-time tillage operations in practical field conditions.

Table 1 Results of soil non-penetration test.

Target Tillage Depth (mm)	10	20	30	40	50	60	70	80	90	100
RMSE (mm)	0.0050	0.1395	0.1630	0.2027	0.4053	0.0184	1.0016	0.0945	3.2757	1.0835
Accuracy (%)	99.2	98.1	98.6	98.8	98.7	99.7	98.5	99.6	97.9	98.9
	9	3	5	7	3	7	7	2	9	6

CONCLUSIONS

This study successfully developed a real-time monitoring system for traditional tillage, with significant improvements in the measuring mechanism using counterweights and spring-guided caster wheels. Field and tests demonstrated the high accuracy and stable performance of the system (low RMSE, accuracy over 98%), especially in complex terrain. The system not only provides an effective depth monitoring solution, but is also easy to integrate, contributing to improving the quality of tillage and optimising the efficiency of mechanised farming.

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