DESIGN OF A CROSS-BOUNDARY WARNING SYSTEM FOR SOIL PREPARATION BASED ON BDS

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基于 BDS 的拖拉机整地作业越界预警系统设计

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ABSTRACT

To address issues wherein tractors easily cross boundaries during soil preparation, a cross-boundary model for front, side and any arbitrary boundary was proposed. Based on BeiDou navigation satellite system (BDS), using John Deere Model 1204 tractor as the hardware platform and LabVIEW2018 as the software development platform, a hierarchical cross-boundary warning system of soil preparation was developed, and field tests under different boundary conditions were carried out. The test results show that the cross-boundary warning system for soil preparation proposed in this study had good judging and warning capacities for front, side and any arbitrary boundaries, with the tractor showing no cross-boundary behaviour during operation, suggesting the proposed system is stable and viable for application.

摘要

针对拖拉机整地作业过程中容易出现越界的问题，本文首先构建了车前、车侧和任意边界的越界预警模型，并基于北斗定位系统，以 LabVIEW2018 为开发平台，设计了一种具有越界预判功能的分级越界预警系统，最后以约翰迪尔 1204 型拖拉机为试验平台，悬挂旋耕机进行实地试验。试验结果表明，本文设计的越界预警系统对于车前、车侧和任意边界都有较好的判别和预警能力，拖拉机均未越界，分级越界预警系统运行整体较为稳定，系统可靠性较高，适用性较强。

INTRODUCTION

In agricultural production, soil preparation is important for improving soil quality and increasing crop yield (*Varela et al., 2014*). A soil preparation machine pulled by a tractor can operate more efficiently if the tractor is able to sense and receive an early warning before a boundary of the operation area is crossed. Similarly, when the vehicle is operating repeatedly in the field, retreading a portion of the operation area can easily occur, resulting in a loss of soil preparation efficiency (*Di X et al., 2010*).

Currently, traditional cross-boundary warning systems are mainly based on machine vision (*Mo H and Farid, 2018, Wang Fengyun et al., 2016*) , which obtains the live video of soil by single and binocular CCD cameras, and extracts a frame image for processing to identify the marking line of the farm road (*Chen et al., 2019, Zhao Liming et al., 2018, Meng Qingkuan et al., 2016*) . For example, the AURORA system developed by Carnegie Mellon University in the United States carries out boundary detection through a colour camera mounted on one side of the vehicle (*Ghasemzadeh A. and Ahmed M.M., 2018*). However, cross-boundary warning systems based on machine vision require a complex computation process and exhibit poor stability (*Hu Liping et al., 2019*). To address this, cross-boundary warning systems based on magnetized iron wire have been put forward, which could judge whether the vehicle has crossed the boundary by detecting the change of the magnetic field using Hall element equipped with a bias magnet (*Zhuo Qing et al., 2016*). The method is simple but requires a large amount of wire to be laid before it can function, so it is not suitable for large-area detection (*Li Dawei, 2011*).

Satellite navigation and positioning technology has advantages of high positioning accuracy, strong real-time performance and low cost, and has been widely used in the regulation of agricultural machinery operation (*Xiong Bin et al., 2017, Sui Mingming et al., 2016, Meichen L. et al., 2018*).

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In this study, a cross-boundary warning system for soil preparation is proposed based on BDS, which could supervise in real-time different cross-boundary conditions and deliver hierarchical cross-boundary warnings by acquiring the cross-boundary distance during soil preparation, enhancing the working efficiency and security of tractor soil preparation.

MATERIAL AND METHODS

Cross-boundary warning modeling

Generally, before the tractor starts soil preparation, the warning boundary is already known and set. According to the demands of actual operation, the boundaries that need to be subject to early warning can be divided into three types, i.e., the front boundary, the side boundary and any arbitrary boundary.

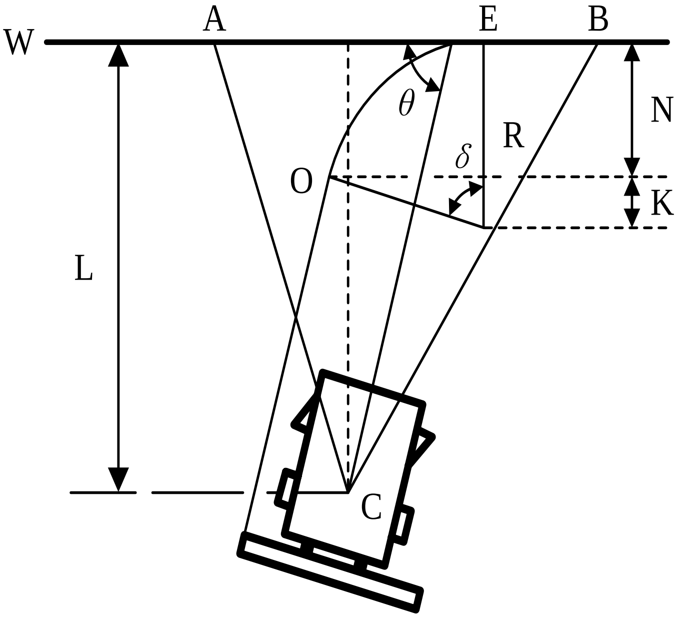


Fig.1 - Vehicle front boundary model

In the triangle ABC, the area S could be solved through equation (1):

$$S = \sqrt{P(P-AB)(P-AC)(P-BC)} \tag{1}$$

Where: *AB* - a length of the triangle, mm;

AC - a length of the triangle, mm;

BC - a length of the triangle, mm;

P - the semi-perimeter of triangle *ABC*, mm.

So, the straight-line distance *L* from point *C* to the boundary line *W* and the minimum cross-boundary warning distance *N* could be solved by equation (2) and equation (3):

$$L = \frac{2S}{AB} \tag{2}$$

$$N = R - R\cos\delta \tag{3}$$

Cross-boundary time *T* could be solved by equation (4):

$$T = \frac{2\times\pi\times R\times\delta}{360\times v} \tag{4}$$

Where: *v* - the forward speed of the tractor, mm/s.

Since the minimum turning radius of the model has been determined, the warning threshold is unique and is the minimum cross-boundary warning distance *N*. The purpose of introducing the cross-boundary time *T* is to evaluate the rotational velocity of the control system motor. When tractor travels much slower, to make the tractor drive steadily and to guarantee the security when the tractor turns, the rotating speed of the motor should be lower (*Shi Tingna et al., 2017*). When the tractor travels at higher speed, the cross-boundary time *T* is short, so the rotating speed of the motor should be relatively higher.

For two cases where the boundary line is located on the side of the tractor or when the boundary line is the boundary of the preparation range of adjacent soils, it will set a cross-boundary warning for the side boundary. As shown in Fig. 2, *C* is the central point of the tractor, *X* and *Z* are two arbitrary points in the side boundary line *W*, *δ* is the wheel turning angle, and *2D* is the operation width of the rotary cultivator.

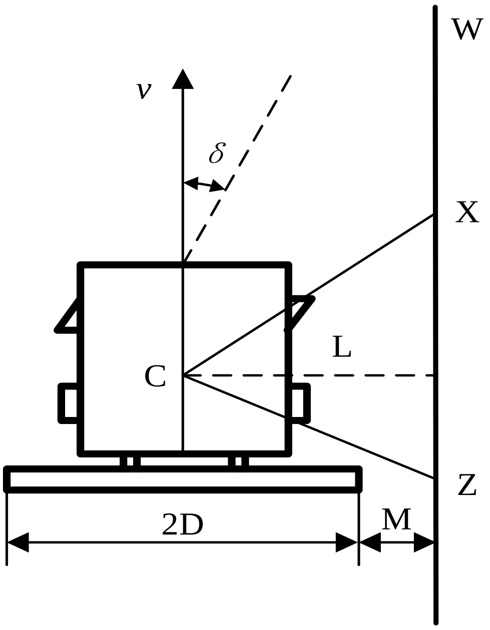


Fig.2 - Vehicle side boundary model

In the triangle CXZ, the area S could be solved through equation (5):

$$S=\sqrt{Q(Q-CX)(Q-CZ)(Q-XZ)} \tag{5}$$

Where: *CX* - a length of the triangle, mm;

CZ - a length of the triangle, mm;

XZ - a length of the triangle, mm;

Q - the semi-perimeter of triangle *CXZ*, mm.

So, the straight-line distance *L* from point *C* to the boundary line *W* and the minimum cross-boundary warning distance *M* are respectively solved by equation (6) and equation (7):

$$L=\frac{2S}{XZ} \tag{6}$$

$$M=L-D \tag{7}$$

Cross-boundary time *T* is solved by equation (8):

$$T=\frac{M}{v\times\cos\delta\times\sin\delta} \tag{8}$$

In this model, the current working path is basically parallel with the completed working path. After the cross-boundary warning occurs, in the event the driver does not correct the driving direction immediately, the system will automatically control the steering motor to correct the driving direction of the tractor.

In an instance where the boundary appears in the planned operation area, such as pits, before the warning system is turned on, the two points in the arbitrary boundary are searched and connected to establish a boundary line by marking the coordinate while the safe distance to be reserved is determined. Using the above two models, any boundary warning could be achieved.

Hardware and software system design

To create a comprehensively functional cross-boundary warning system for tractor soil preparation, it is necessary to design comprehensively its hardware and software systems.

We used a John Deere Model 1204 wheeled tractor as the platform, making use of the existing BeiDou positioning system and the steering control system, to construct the proposed tractor cross-boundary warning hardware system, as shown in Fig. 3.

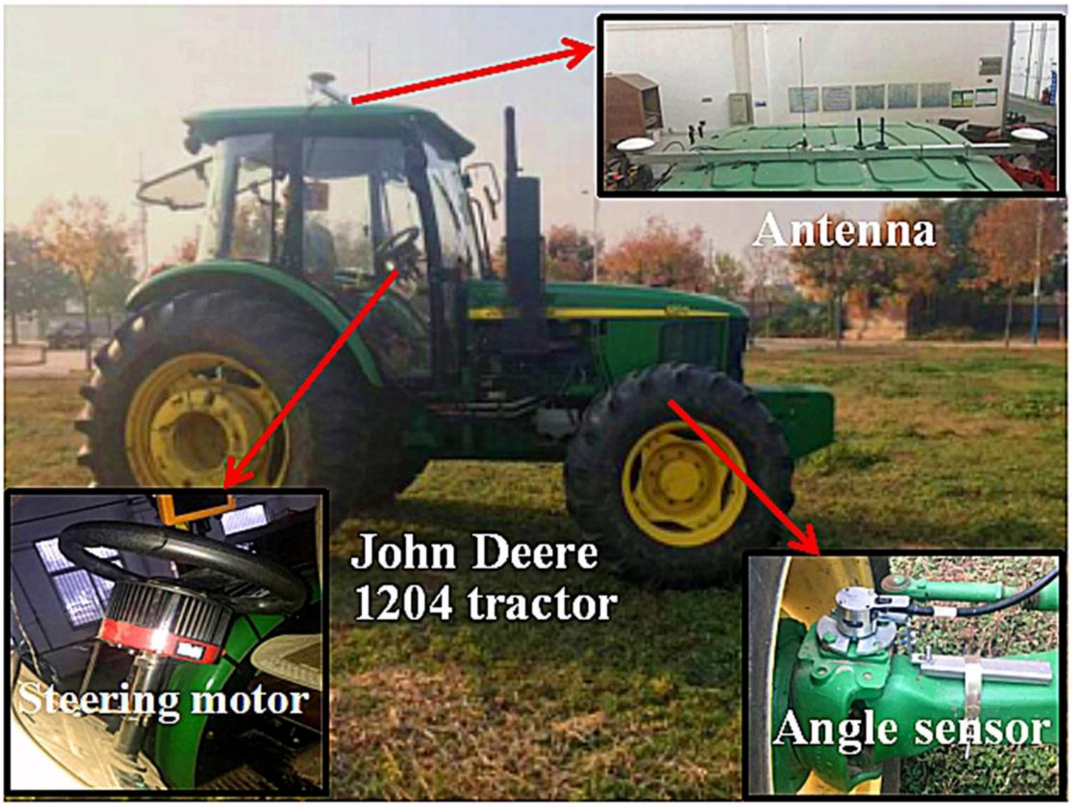


Fig. 3 - Platform of tractor cross-boundary warning system

The platform has 9 standard equipped forward gears and 3 backward gears; therefore, different gears may be selected as required by different working conditions.

The main technical parameters of the hardware system are shown in Table 1.

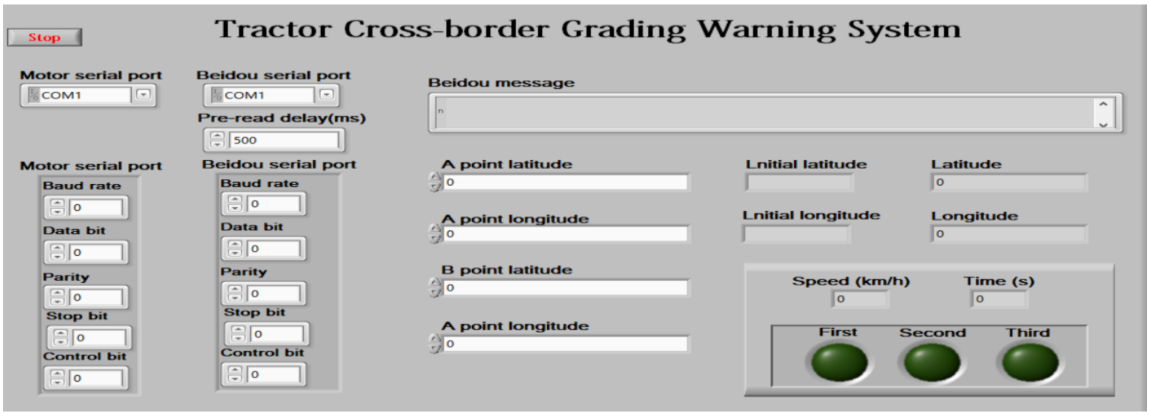
Table 1

Main technical parameters

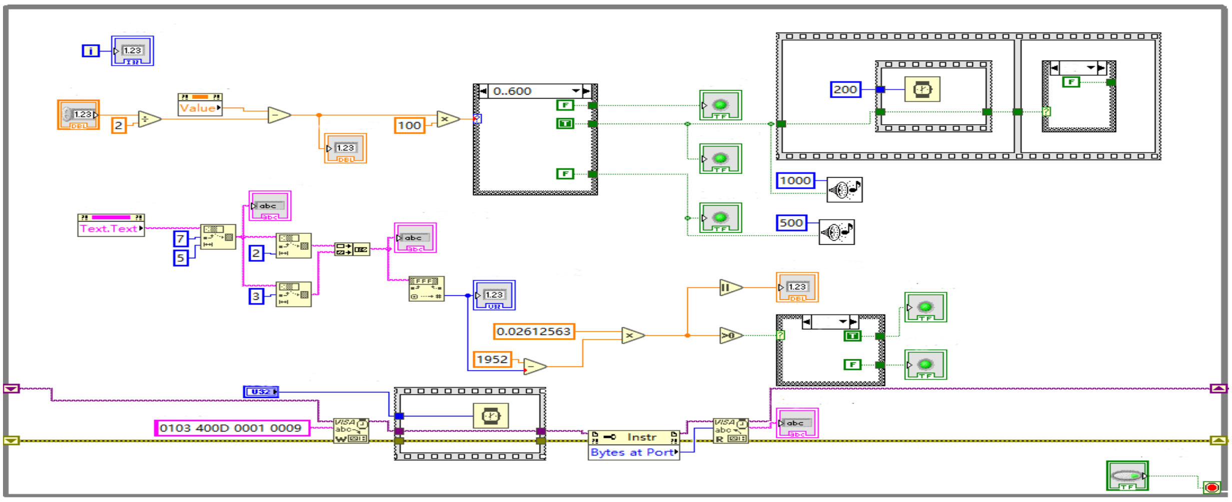
Name	Model	Parameter
Integrated navigation and positioning system	UM220-INS N	±2cm
Front angle sensor	424A16A090	±40°
Permanent magnet brushless DC motor		1500 r/min, 19 Nm

LabVIEW2018 was the development platform. We adopted a modular approach and developed four main subroutines for the BeiDou positioning system, speed measuring system, front wheel angle acquisition system and motor steering control system according to the predetermined functions described above.

Fig. 4 depicts the main cross-boundary warning system for tractor soil preparation, wherein Fig. 4(a) is a user interaction interface, and Fig. 4(b) is a block diagram. The wheel steered angle interface displays mainly the steering information from the tractor, in which the steering direction is indicated by the illumination of two Boolean lights and the steering value is displayed by the data bar. The cross-boundary parameter interface displays three major pieces of information: vehicle speed, cross-boundary time and cross-boundary distance. This interface allows the driver to view the current cross-boundary parameters of the vehicle in real time. The warning light interface uses three Boolean lights to display three-level cross-boundary warning information, with red, orange and yellow warning lights indicating respective cross-boundary distance warning levels.



(a) Version of the cross-boundary warning system



(b) Three-level warning rear panel

Fig. 4 - Tractor cross-boundary warning software main system

RESULTS

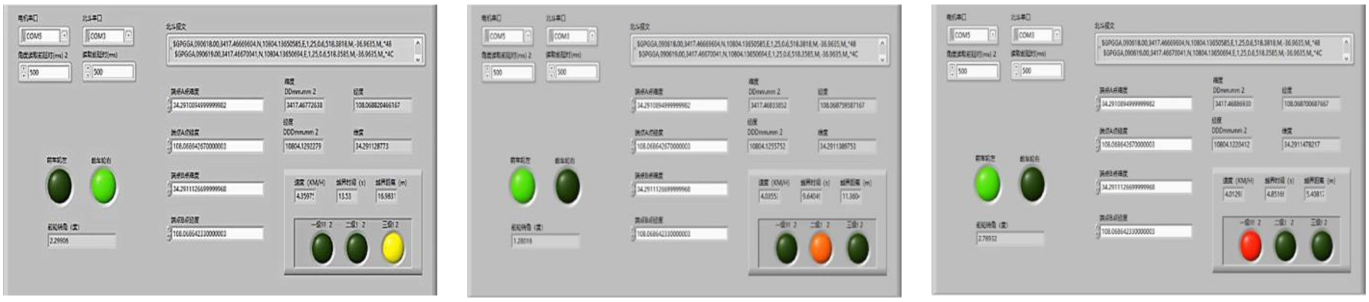
In order to verify the performance of the cross-border warning system for soil preparation, individual vehicle front boundary, side boundary and arbitrary boundary cross-border warning tests were carried out.

Cross-boundary warning test for front boundary

The test site selected was on empty soil at Northwest A&F University. Five red signposts and tape measures were set on the test site as warning distance markers. Standard warning distances of 6m, 12m and 18m were measured and determined by tape measure, and two vertical rods were set at the end to simulate the front boundary of the vehicle, as shown in Fig. 5.

Fig. 5 - Front boundary test site layout

The tractor continually approached the front boundary travelling normally. When it arrived at the vertical rod at 18m, the third-level warning light turned on, as shown in Fig. 6 (a), indicating the tractor began to enter its alert state. When it arrived at the vertical rod at 12m, the second-level warning light turned on, as shown in Fig. 6(b), indicating that the rotary cultivator could be damaged in the event the tractor was using wide-angle steering during soil preparation. When the tractor arrived at the vertical rod at 6m, the first-level warning light turned on and the tractor turned with its minimum turning radius and the motor rotated clockwise, driving the front wheel towards the right, as shown in Fig. 6 (c).



(a) Three-level warning interface *(b) Secondary level warning interface* *(c) First level warning interface*

Fig. 6 - Hierarchical crossing warning interface

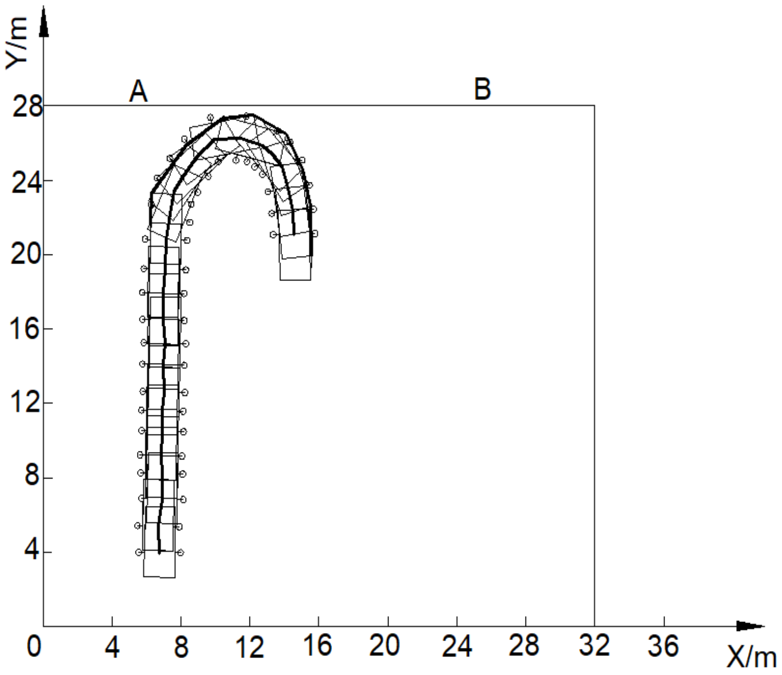


Fig. 7 - Tractor actual walking route

The position of the tractor was recorded in real time by the BeiDou satellite locator and the actual travelling route map was recorded, as shown in Fig. 7. The tractor's travel path and its outer wheel path with the minimum turning radius were marked with thick lines.

After 10 iterations of the front cross-boundary warning test, it was determined that the minimum distance between the tractor's turning path to the front boundary was 13cm. The overall operation of the cross-boundary warning system was relatively stable and highly reliable.

Cross-boundary warning test for side boundary

The selected test site was mud soil at Northwest A&F University. Six red signposts were used to simulate the side boundary of the vehicle, as shown in Fig. 8. In this test, the operation width of the mounted rotary cultivator was 2.8m and the boundary distance thresholds were set as 0.4m, 0.8m and 1.2m.

Fig. 8 - Vehicle side test site layout

As the driver drove the tractor toward the side boundary of the vehicle, the cross-boundary distance gradually decreased. When the cross-boundary distance was less serially detected as less than 1.2m and then 0.8m, the system entered respectively the third-level and second-level warning and the warning lights for third-level and second-level warning turned on in sequence. When the final cross-boundary distance was less than 0.4m, the first-level warning light turned on and the system controlled the motor to steer the tractor.

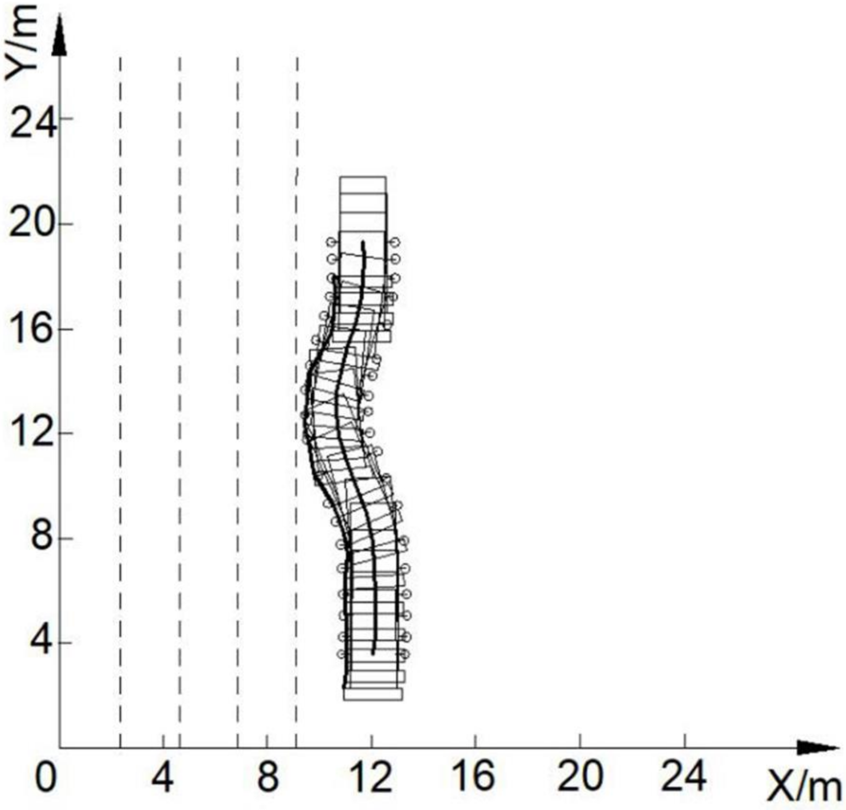


Fig. 9 - Tractor actual walking route

Figure 9 shows the recorded actual travelling route of the tractor from the experiment, in which the travel path of the tractor and the working track of the rotary cultivator are marked with thick lines. The figure indicates that when the driver drove the tractor awry of the intended prepared area the system controlled the motor to steer to the opposite direction upon entering the first-grade alert state in order to prevent the tractor from crossing the boundary.

Cross-boundary warning test for arbitrary boundary

The selected test site was soil at the Northwest A&F University. A simulated pit was set in advance on the tractor’s path. As shown in Figure 10, the vertical rod at the right marked the centre of the simulated pit and the rod at the left marked the boundary of the driving area. The safe radius was set as 0.3m and the three levels warning distance thresholds from most to least alert were 0.3m, 0.6m and 0.9m, respectively.

Fig. 10 - Arbitrary boundary warning test site layout

During normal driving of the tractor, the cross-boundary warning system judged the cross-boundary distance between the tractor and the pit in real time. When the tractor drove within 0.9m and 0.6m warning distances, the third-level and second-level lights turned on. When the tractor drove within the scope of 0.3m, the first-level warning light turned on.

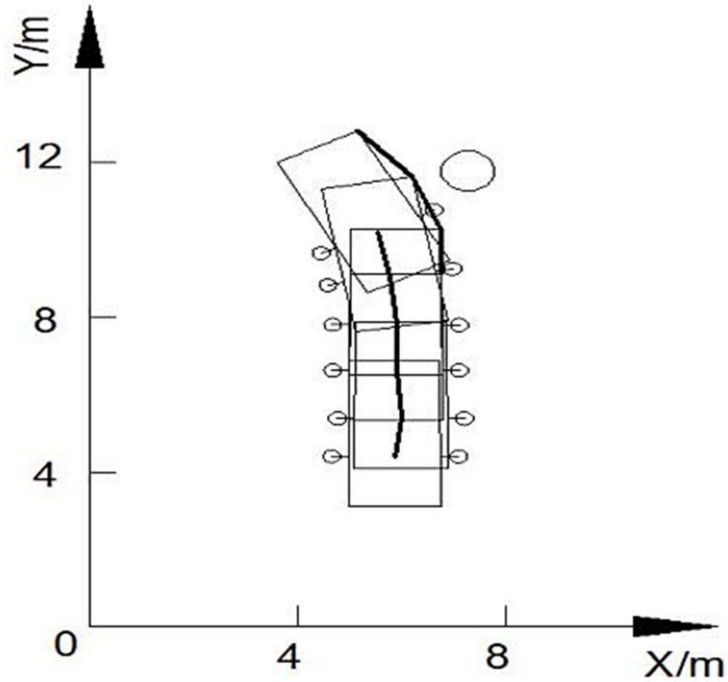


Fig. 11 - Tractor actual walking route

Figure 11 shows the recorded actual travelling route of the tractor from the experiment, in which the travel path of the tractor and the outer wheel turning path of the tractor are marked with thick lines. The figure shows that when the tractor approached the pit on the right, the system controlled the motor rotate clockwise upon entering the first-level warning region so that the tractor bypassed the pit smoothly.

The cross-boundary warning test for an arbitrary boundary showed that the cross-boundary warning system effectively operated as intended according to the actual conditions in the operation area.

CONCLUSIONS

To address potential risks during the process of soil preparation, a hierarchical cross-boundary warning system based on the building of cross-boundary warning model was proposed. It extracted the cross-boundary information of the tractor by acquiring the real-time positioning information of the tractor via BDS, the tractor's soil preparation speed and the steering angle. When the tractor entered the first (highest) warning state, the system automatically controlled the motor to shift so that the tractor bypassed the boundary or hazard. In this study, the relevant field tests were conducted with a John Deere Model 1204 tractor mounted rotary cultivator as the test platform. The test results show that the hierarchical cross-boundary warning system was generally stable and is viable for further application.

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