Development of key components of wheel tractor driving simulator based on desktop virtual reality

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Abstract. The wheel tractor driving simulator was developed by using desktop virtual reality technology to solve the problems of short training times and complex operation for drivers, which led to machine damage and low efficiency when the wheel tractor was used. Firstly, the composition of the tractor driving simulator and its working principle were presented. Secondly, combined with the obtained parameters and operation requirements, the key components of the wheeled tractor driving simulator were designed. Finally, the high-degree simulation of the wheeled tractor driving simulator was verified by comparing the parameters of the key components of the real tractor with those of the wheeled tractor driving simulator. The test results showed the stroke angle and feedback force of the simulator were basically the same as that of the real tractor and they had the same trends. Therefore, the key components of the wheeled tractor driving simulator designed in this paper can simulate the driving body sense and operational functions of real tractors. The development of a driving simulator is of great significance to train unqualified drivers, improve training efficiency and reduce training cost.

1. Introduction

With the annual improvement of agricultural mechanization and the promotion of joint operation machines in China, the demand for high-power tractors increases year by year [1,2]. The use of high-power tractors can reduce the number of workers and increase income at the same time. The use of high-power tractors can reduce the number of people working in the field while increasing revenue. In particular, the use of high-power tractors during deep tillage operation can conserve water and reduce runoff, thus achieving the purpose of environmentally friendly planting [3-5]. However, in actual operation, the phenomenon of failure or even abandonment of high-power tractors often occur due to improper operation of the tractors by drivers or failure to operate the tractors as required, which increases production costs and delays agricultural production [6]. In view of the above problems, the virtual reality technology should be introduced into agricultural equipment informatization and applied to the wheeled tractor driving system to develop a wheeled tractor driving simulator for training [7]. Overseas studies on driving simulators are relatively early. Taking Vehicle Driving Simulators as an example, a number of them have been applied to the research on vehicle driving training and vehicle system [8-12]. From 1993 to 1996, the researchers at the America Traffic Safety Service Association and University of Iowa jointly built the "national advanced vehicle driving simulator (NADS)" system, which had 13 degrees of freedom and could simulate a variety of road conditions and driving environments[13-14], but its complex structure and expensive price were not suitable for driving training. The research on driving simulator in China was relatively late [15-17]. In 1996, researchers at
2. Principles and methods

2.1 The wheeled tractor driving simulator

The wheeled tractor driving simulator designed in this paper takes ACGO 1204 tractor as the design prototype and is based on “Car Driving Training Simulator (JY/T 378-2014)” in the current standard of transportation industry in the People's Republic of China. The wheeled tractor driving simulator was mainly composed of a software part, a data acquisition device and a hardware part. The software part and data acquisition part is based on the Driving Simulation System V1.0 of Large Tractor and the Desktop Simulation Training Software V2.0 of High-power Wheeled Tractor independently developed by Heilongjiang Bayi Agricultural University. The hardware part was mainly composed of a computer, a display system, a steering system, a walking system and an operating handle system. The wheeled tractor driving simulator designed in this paper is shown in Figure 1.

![Figure 1: The wheeled tractor of driving simulator.](image)

2.2 Working principle

After the wheeled tractor driving simulator is started, the information acquisition device collects the operator's control signals, converts them into electrical signals, and then transmits them to the data acquisition system for signal conditioning and data processing. Then the data was processed according to the calibrated communication protocol through the communication interface and transmitted to the computer. According to the received data, the computer can change the motion state of the tractor dynamic model in the virtual training software. Combined with relevant operations of drivers, signal lights, sounds, video and other modules can generate corresponding feedback, making the driving feel more real. The schematic diagram of the wheeled tractor driving simulator system designed in this paper is shown in Figure 2. The part shown in the dotted line is the core content of this paper, and it is also the main source of driver's sense of body.
3. Design of key components of wheel tractor driving simulator

3.1 Design of the walking system

To make the wheeled tractor driving simulator have real tractor operating functions and body feeling, its structure and working principle of the walking system were designed according to AGCO 1204 tractor. According to the relevant parameters (stroke angle and feedback force) of the walking system of AGCO 1204 tractor, the mechanical structure, dimensions, mounting position and design requirements of the four pedals were determined. The structure diagram of the simulator walking system designed in this paper is shown in Figure 3.

The clutch pedal and two brake pedals of the wheeled tractor driving simulator were both supported by a back shaft and fixed on the back shaft through the sleeve. And the pedal could rotate a fixed angle around the back shaft under the limit of the limited rod. When the operator steps on the clutch or brake pedal, the pedal drives the end magnetic steel of the connecting rod to move. The change in displacement can be measured by this acquisition device. If the operator releases the pedal, the tension of the spring will make the pedal automatically return to its original position. The design of the pedal is Floor-standing, which is the same as that of the AGCO 1204 tractor. It was connected with pedal rod and side rod, and the magnetic steel was fixed at the end of the pedal rod. By converting the angle change of the accelerator pedal into the linear change of the connecting pedal rod, the angle of the pedal was obtained after measuring the displacement of the pedal rod. In the wheeled tractor driving simulator walking system, the rotation angles of the clutch pedal, the brake pedal and the accelerator pedal are 40°, 20°, 20°, respectively. The center distance of each pedal was designed to be 155mm for the accelerator pedal and the brake pedal, 120mm for the two brake pedals, and 180mm for the brake pedal and the clutch pedal. According to the pedal force value of the AGCO 1204 tractor, it was calculated that the accelerator and brake pedal springs are respectively selected from 35×15×1.8mm and 50×18×2mm (the maximum stroke is 50mm and 85mm). Since the clutch pedal stroke is large and the pedal force is suddenly increased at the clutch position, a 50×12×2 mm and a maximum stroke of 120 mm high tension spring are selected.
3.2 Design of steering system

The steering system of the tractor driving simulator was designed based on the measured ACGO 1204 tractor steering system parameters and the simulator industry standard JY/T 378-2014. The schematic diagram of the designed steering system is shown in Figure 4.

![Figure 4. Schematic diagram of steering mechanism](image)

In the design of steering system, steering wheel, cardan joint and other components are purchased in accordance with the standard. The steering gear is a rack and pinion structure, which has the characteristics of simple structure, high transmission efficiency, and can also change the axial rotation of the steering wheel into the linear reciprocating movement of the rack. The working principle is as follows: the axial rotation of the steering wheel transfers the torque of the steering wheel to the steering wheel through the steering column. When the gear shaft drives the rack to reciprocate in a straight line, the connecting rod with magnetic steel is also driven to reciprocate left and right, so as to realize the acquisition of steering wheel rotation angle. Spring is evenly distributed on both sides of steering wheel. As the steering wheel turns, the spring is compressed to produce a force in the opposite direction. The reaction force of the spring causes the steering wheel to return to normal without external force. In addition, the maximum stroke of the rack is used to define the maximum angle at which the steering wheel can be rotated by 1440°.

3.3 Design of operating handle system

ACGO 1204 tractors have a variety of operating handles, such as gear handles, hydraulic handles, hand throttle, hand brakes. Because the hand-brake and hand-throttle mechanisms are modified by the purchased parts of the real machine, the operating handle system of the tractor driving simulator designed in this paper is only designed according to the function of the variable speed control mechanism. In addition, since the control mechanism has a small impact on the sense of motion of the driver, the parameters (strength and stroke) of the operating handle system are not collected. The gear shifting mechanism of ACGO 1204 tractor has many gears, which is complicated shifting mode (there are two gear shifting devices: main gear shifting and vice gear shifting mechanism), so the two gear shifting devices are designed separately.

3.3.1 Design of main gear shift mechanism for wheeled tractor driving simulator.

The main gear shift device of the simulator is designed according to the main gear shift mechanism of ACGO 1204 tractor, as shown in Figure 5. And it has five gears, which are R (reverse gear), N (neutral gear), 1, 2 and 3.

![Figure 5. The main shift device of simulator](image)

When shifting operation is carried out, the operator pushes the shift lever to rotate a certain angle
along the axis around the locating pin, and then push or pull the shift lever forward to make it into the corresponding gear of the guide slot, so that the information acquisition device can generate electrical signals. Under the action of spring force, the ball head of spring plunger slides into the groove above or below from the middle position (into the self-locking state) to ensure the gear position remains unchanged.

When the shifting operation is released, the operator pushes forward or pulls back the retracting lever to make it out to neutral position. During this process, the shift lever could move back to the neutral position, because it is subject to the elastic force of spring plungers on both sides. After repeated tests, the main shifting mechanism of the wheeled tractor driving simulator designed in this paper meets the design requirements and functional requirements.

3.3.2 Design of vice gear shift mechanism for wheeled tractor driving simulator.

The main vice shift device of the simulator is designed according to the vice gear shift mechanism of AOGO 1204 tractor, as shown in Figure 6. And it has five gears, which are “tortoise gear”, “rabbit gear”, high gear, low gear, and N (neutral gear).

![Figure 6. The vice shift device of simulator](image)

When shifting operation is carried out, the operator pushes forward or pulls back the shift lever to drive the slider of “tortoise and rabbit” to rotate along the axis by a certain angle, so that the end of the shift lever rotates by the same angle and slides to the corresponding gear position in the guide slot. Under the action of the spring force, the ball head of the spring plunger falls into the self-locking slot and enters the self-locking state. After changing the gear position of “tortoise and rabbit”, as the shift lever is affected by the spring plunger, the shift lever will spring back to neutral position. The operator pushes the shift lever to the right to slide it into the slider of the high and low gear, and then pushes the shift lever forward or backward to shift into the high or low gear. Thus far, the shift of vice gear combination of the driving simulator is completed.

Reverse the gear according to the order of first retracting the high and low gear: as the slider is pushed, the spring plunger slides out of the lock slot and back into the middle self-locking slot, and then the operator pushes the gear lever into the “tortoise and rabbit” gear slider to retract the gear.

3.4 Design of visual system

In order to facilitate the driver to observe the operation and motion state of the tractor from various angles, three perspective modes are constructed in the software as shown in Figure 7.

![Figure 7. Three perspective modes](image)

Hence, the visual system consisted of graphic cards (NVIDIA GeForce 980M), an Intel Core i7-7560 processor (MDP2HDS, and a solid state disk).
4. Verification and discussion

4.1 Verification of walking system of tractor driving simulator

By collecting the parameters (angle and force) of each pedal in the walking system of tractor driving simulator and comparing them with those of ACGO 1204 tractor pedal, the simulation of the walking system of tractor driving simulator was verified.

![Image of pedal installation](image)

Figure 8. The installation position of MPU6050

| Measuring object/Angle range | Angle     |
|------------------------------|-----------|
| Accelerator                  | 0~20°     |
| Brake                        | 0~20°     |
| Clutch                       | 0~40°     |

The Angle stroke obtained was averaged for 3 times and rounded to the nearest decimal point. The unit is degree.

4.2 Verification of the pedal feedback strength of the walking system.

The pedal stress acquisition device designed in this paper and the MPU6050 gyro are simultaneously fixed on each pedal of the tractor driving simulation. The installation position is shown in Figure 9. The test results are drawn as a line chart and compared with the feedback force curve of each pedal collected by ACGO 1204 tractor, as shown in Figure 10.

![Image of pedal installation](image)

Figure 9. Equipment installation location diagram

![Graph of pedal forces](image)

(a) The accelerator pedal
According to the comparative analysis of the feedback force curve, the feedback force of the tractor driving simulator accelerator pedal is slightly different from that of the real tractor accelerator pedal when the feedback force is $5^\circ \sim 10^\circ$, but the overall trend is basically the same. The brake pedal force of tractor driving simulator basically has the same trend as that of ACGO 1204 tractor. For the clutch pedal of tractor driving simulator, ACGO 1204 tractor's clutch is of mechanical structure, so it is difficult for the tractor driving simulator to simulate the real pedal force. However, the comparison of the force feedback curve shows that the clutch pedal force designed in this paper still has a similar trend to that of ACGO 1204 tractor. The comparison above proves that the walking system of tractor driving simulator designed in this paper can well simulate the operating body sense of ACGO 1204 tractor walking system.

5. Conclusions
The simulation of the walking and steering system of the wheeled tractor driving simulator designed in this paper is verified by comparing the parameters of the walking and steering system of the ACGO 1204 tractor with that of the wheeled tractor driving simulator designed in this paper. It is verified by experiments that the stroke angle and feedback force of the simulator walking system are basically the same as the real tractor walking system and have the same trend. The steering system is slightly deviated from the effective steering angle of the real tractor steering system, but still meets the requirements of the national simulator standard. Therefore, the key components of the wheeled tractor driving simulator designed in this paper can simulate the driving sense of real tractor.

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References
[1] Guo, R. (2014) Modeling and control simulation of multi-stage hydraulic mechanical continuously variable transmission of wheeled tractor. Henan University of Science and Technology.
[2] Jin, Y. (2010) The fierce competition in the big wheel industry. Agricultural Machinery Market., 02: 28-30.
[3] Zhang, J.F. (2015) Research on the development status of large horsepower tractor. Agricultural Machinery Use and Maintenance., 07:1-3.
[4] Mao, P.J., Gao, W.J., Li, S.L. (2011) Research on the development status of large horsepower tractors. Agricultural Equipment and Vehicle Engineering., 07:1-3.
[5] Yang, J.W. (2015) The demand of high horsepower tractors from the development trend. Agricultural Machinery and Maintenance., 05:62.
[6] Jiao, H.P. (2010) Common Usage of Maintenance and Selection of Large Horsepower Wheeled Tractor. Friends of Farmers' Riches., 12: 64.
[7] Zang, Y., Zhu, Z.X., Song, Z.G., (2010) Establishment of virtual equipment system platform for agricultural equipment. Transactions of the Chinese Society of Agricultural Machinery., 09: 70-74+127.
[8] Zhang, W.W. (2012) Research on real-time force simulation of steering simulator steering wheel. Zhejiang University.
[9] State Key Laboratory of Automotive Dynamic Simulation. (2002) Introduction to Developmental Driving Simulator Technology. Journal of Jilin University., 03: 1-9.
[10] Yang, S.M., Kim, J.H. (2012) Valdation of the 6-DOF vehicle dynamics model and ITS related VBA program under the constant radius turn manoeuvre. International Journal of Automotive Technology., 04: 593-605.
[11] Terumitsu, H., Tetsuo, Y., Tsuyoshi, T. (2007) Development of the Driving Simulation System MOVIC-T4 and Its Validation Using Field Driving Data. Tsinghua Science and Technology., 02: 141-150.
[12] Lange, C., Bengler, K., Spies, R. (2011) Development of Distraction-free control systems in a Driving simulator. Electronics Infotainment., 05: 25-27.
[13] Anna, D., Jane, M., Judith, C. (2012) Investigating driving behavior of older drivers with mild cognitive impairment using a portable driving simulator. Accident Analysis and Prevention., 06: 24-27
[14] Zhou, Z. (2008) Aesthetic pleasure created by virtual reality speed technology system. Harbin Institute of Technology.
[15] Tang, Z.H., Zuo, T.L., Zhou, M.Y., (2006) Application of Vehicle Driving Simulator in Traffic Engineering. Journal of Southwest Jiaotong University.,05:630-634.
[16] Fan, Z.W., He, X.L., Jiang, D. (2004) Research Status and Future Prospect of Automobile Driving Model Finder. Automotive Applications., 10: 31-32.
[17] Wu, Y.W., Pan, W.C., Wang, J.G. (1995) MULQJM Automobile Driving Simulator System. Journal of System Simulation., S1: 19-24.
[18] Wu, X.R., Wu, Z.Z. (2015) A Review of the Application of Vehicle Driving Simulator in Traffic Safety. Traffic Information and Safety., 02: 10-19.
[19] Xu, Z.F. (2013) Application development of road safety evaluation based on UC-win/Road. Southeast University.
[20] Yu, F.Q., Shen, X.L., Zhou, X.G. (2014) Design of Flight Simulation System for a Shipborne Helicopter Flight Simulator. Computer Simulation.,09: 67-70+83.
[21] Liang, Gao.J. (2012) Application of Large-scale Jianghai Ship Simulator in Inland River Driver Training. China Water Transport (2nd Half)., 02: 15-16.

[22] Yu, T.C. (2016) Design of virtual driving training system for high power tractor. Heilongjiang Bayi Agricultural University.