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Development of a General-Purpose Test Platform for Agricultural Navigation

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ABSTRACT

Field tests are necessary in establishing navigation models and algorithms for agricultural vehicle robots. And it costs much to use tractors or combine harvesters as the platform in terms of system modification, routine maintenance and fuel consumption. The objective of this research was to develop a general-purpose test platform for conducting experiments in agricultural autonomous navigation at a low cost based on a commercially available electric vehicle. A brushless motor was utilized as the power source for automatic steering. An analog PID controller was designed to compare steering commands and actual steering angle and calculate an appropriate voltage signal as the input of the motor driver. A rotary encoder was attached to the driving wheel and a digital PID controller was implemented to determine the throttle value in real-time in maintaining the test platform at a desired speed. A CAN-bus network was established to integrate the automatic steering system and the speed control system as two nodes for information communication. And a CAN node interface was reserved for receiving commands from autonomous navigation systems to be evaluated. Field tests showed that RMS errors were 2.6 cm and 0.054 m·s-1 for lateral offset and speed control, respectively, in tracking straight paths, which indicated that the newly developed test platform met requirements for agricultural navigation experiments.

Keywords: Agricultural robots; Autonomous navigation; Test platform; Field tests

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1. Introduction

Along with development of large-scale production in agriculture, it becomes increasingly necessary to realize precision management and automatic control of off-road vehicles including tractors and combine harvesters, which is an important research field in precision agriculture [1-3]. Autonomous navigation of agricultural vehicles has been applied to different stages of an agricultural cycle including soil tillage, seeding, fertilizer and pesticide application, transplanting and harvesting under both structured and unstructured environments [4-7]. Some researchers utilized RTK-GNSS and inertial measurement unit (IMU) as navigation sensors for global positioning to develop autonomous navigation systems and conducted experiments on tractors in the field to evaluate their performance [8-10]. Laser range finders were introduced for local positioning under structured conditions to guide agricultural vehicle robots along target paths that were recognized by using predetermined identification algorithms [11-12]. Xue et al. (2012) and Cho et al. (2014a) detected uncut crop edge for automatic guidance of combine harvester based on machine vision[13-14]. Besides, multiple sensors were combined or fused by researchers to achieve comprehensive representation of the target field area [15-17]. Cho et al. (2014b) proposed to utilize multiple navigation sensors including a real-time kinematic global positioning system (RTK-GPS), a GPS compass and a laser range finder to acquire a three-dimensional map of the terrain and used random sample consensus to detect the uncut crop edges, along which the combine harvester would be guided [18].

In order to improve working efficiency in farming, many researchers have been focusing on collaborative operation of multiple agricultural robot vehicles. Noguchi et al. (2004) and Chi Zhang et al. (2016) established a leader–follower system incorporating two tractors that cooperated with each other while separately conducting farm work in the same field [19-20]. Experiments for evaluating navigation systems mentioned above were implemented on tractors or harvesters, which was of high cost in terms of system modification, daily maintenance and fuel consumption and had potential threats to safety of participants including researchers and machines on the scene. Therefore, this research proposed a solution to establishing a general-purpose electric vehicle platform for conducting experiments in agricultural autonomous navigation at a low cost by using the chassis of a commercially available electric vehicle. Automatic control devices were installed on the test platform to realize automatic steering and speed control instead of manual operation. To verify its performance, the newly developed test platform was integrated with an autonomous navigation system by the laboratory of vehicle robotics of Hokkaido University.

2. Material and methods

The test platform was equipped with a 48 VDC, 3 kW driving motor and an electrical control system as shown in Figure 1.

Figure 1 Text platform and GNSS receivers

Basic functions were by-passed for automatic control by referring to Yin X et al. (2014), including controlling of the throttle depth, key switch, change between forward, reverse and stop. The RTK-GNSS positioning system was composed of two Trimble BD970 receivers and antennas as the rover station and base station, respectively.

2.1 Automatic steering system

Automatic steering is a fundamental feature of an agricultural vehicle robot that functions autonomous navigation. Figure 2 shows the automatic steering system comprised mainly of a steering ECU, a PID controller, a steering motor, a motor driver and a potentiometer. The motor driver controls the rotation direction and speed of the steering motor according to the input voltage command V_C. When V_C becomes larger from 0 to +5 V, the steering motor rotates in one direction from the still status to its maximum speed. And it rotates in opposite direction when V_C is of a minus value.

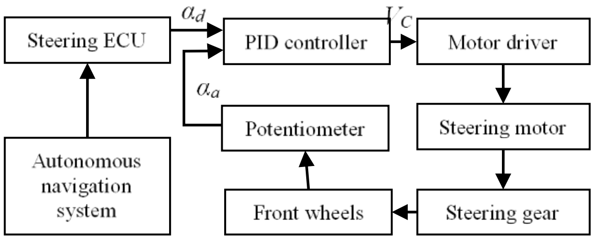


Figure 2 Automatic steering system

To make the structure compact, a 24V/180W motor and reducer was introduced by using a universal joint to connect it with the original steering gear assembly as shown in Figure 3.

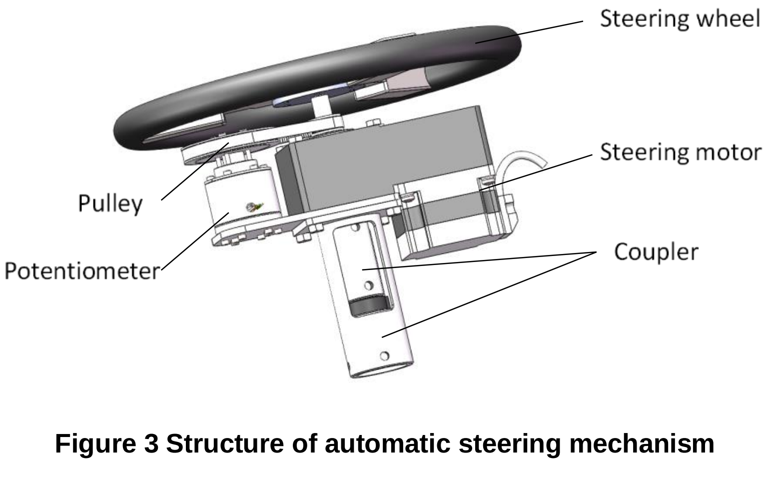


Figure 3 Structure of automatic steering mechanism

The potentiometer was a touchless magnetic sensor with its transducer fixed and the magnet rotated by the steering wheel through pulley transmission to directly feedback the actual steering angle α_a in voltage as depicted. The steering ECU received the steering command in digital from the autonomous navigation system and converted it into a voltage value as an input of the PID controller. For its use in general purpose, the steering ECU was designed and programmed to receive and parse information from the RS232 port or the CAN port as shown in Figure 4.

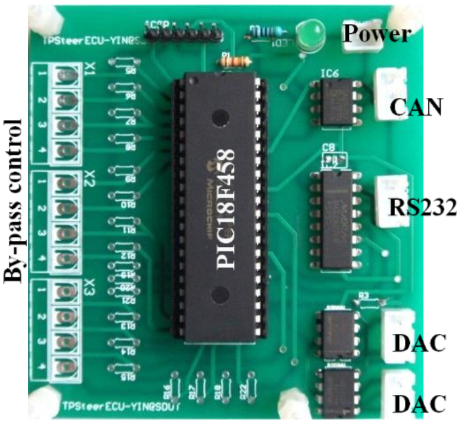


Figure 4 Steering ECU board

The PID controller compared α_a and α_d, calculated an appropriate voltage signal according to Equation (1), and output it to the motor driver. Figure 5 shows the circuit board mainly containing OP07 amplifiers, resistors and potentiometers.

$$V_O=k_P\cdot\Delta V + k_I\cdot\int\Delta V\,dt + k_D\cdot d\Delta V \qquad (1)$$

where k_P, k_I, k_D denote coefficients for proportional, integral, and derivative terms, respectively, and $\Delta V = \varphi_d - \varphi_a$.

Figure 5 PID controller board

2.2 Speed control

Movement of agricultural vehicles in the field is severely disturbed by ground unevenness and soil structure. It needs real-time adjustment of driving power output to maintain a desired speed. Figure 6 shows the diagram of the speed control system.

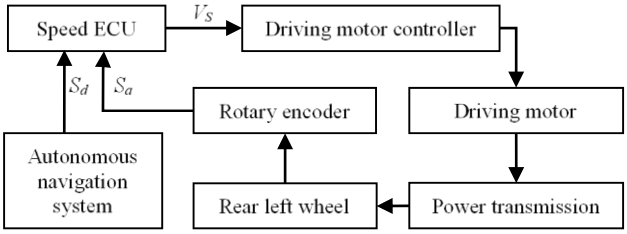


Figure 6 Speed control system

The speed ECU is comprised of a counter CD4040 to receive pulses from the encoder, a CAN port and a RS232 port for information communication as shown in Figure 7. A digital PID controller was implemented in the speed ECU to compare the desired speed S_d and the actual speed S_a and determine an appropriate value for the throttle depth V_S.

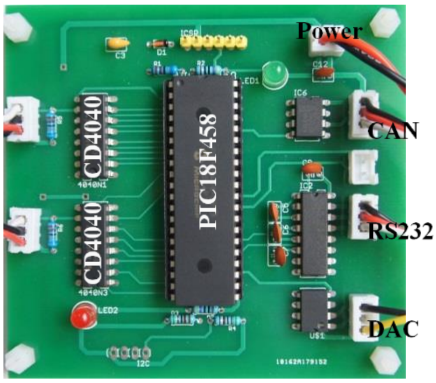


Figure 7 Speed ECU board

The actual speed S_a is calculated by using Equation (2).

$$S_a = \frac{\pi DP}{NT}, \quad (2)$$

where D is the wheel diameter, N is the number of pulses per revolution of the rotary encoder, and P denotes the pulse number counted by CD4040 within the time interval T.

For convenience in system integration, a CAN-bus based communication network was established for receiving navigation commands from the autonomous navigation system or other devices as shown in Figure 8.

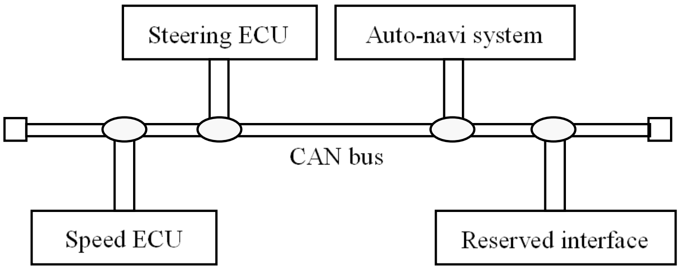


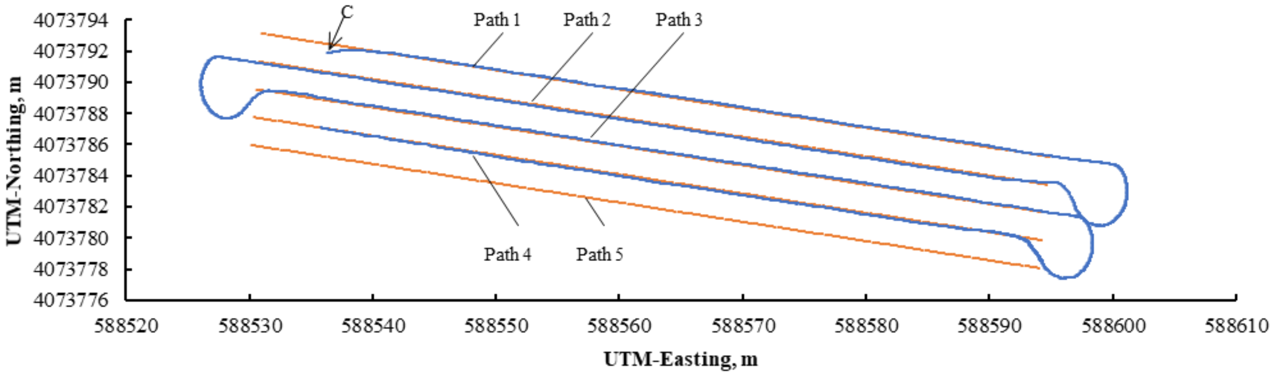
Figure 8 CAN-bus communication network

3. Results and discussion

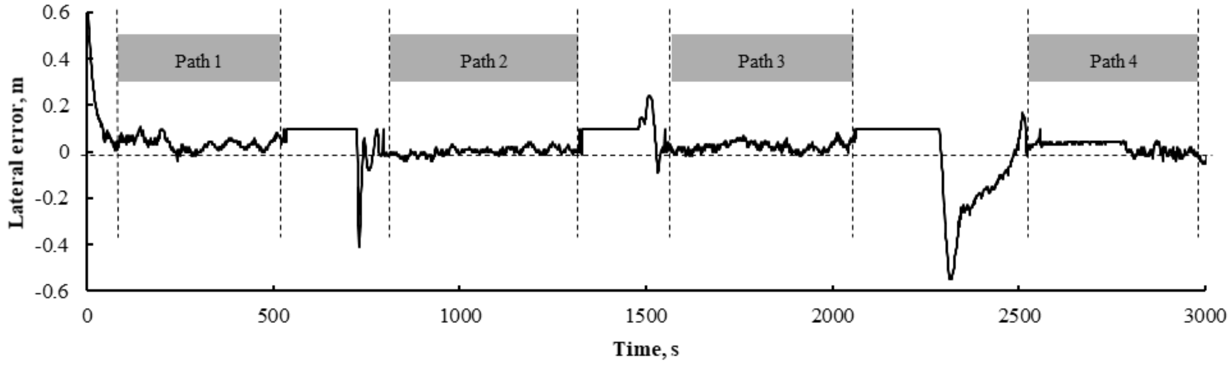
An autonomous navigation system was integrated into the newly developed general-purpose test platform by sending steering and speed commands through the CAN-bus network, which was developed based on fusion of RTK-GNSS and IMU by Shandong University of Technology. Experiments were conducted on campus of Shandong University of Technology located at (117.993°E, 36.806°N).

As shown in Figure 9 (a), the navigation map consisted of five paths and the path following order was set as Path 1 – Path 2 – Path 3 – Path 4 – Path 5. The test platform started autonomous navigation at C (588536.383 m, 4073791.947 m) to follow paths by a desired moving speed of 0.55 m·s-1 and make automatic turns at headland. Four paths were finished due to obstacles on Path 5. Figure 9 (a) shows the actual trajectory on the navigation map. And Figure 9 (b) and (c) show variation of the lateral error and moving speed, respectively. Maximum lateral errors were 0.09 m, 0.10 m, 0.10 m and 0.08 m, the average values were 0.036 m, 0.002 m, 0.022 m and 0.002 m, and RMS errors were 0.026 m, 0.016 m, 0.019 m and 0.026 m for the four paths, respectively. The average values of Sa were 0.56 $m\cdot s^{-1}$, 0.57 $m\cdot s^{-1}$, 0.57 $m\cdot s^{-1}$ and 0.57 $m\cdot s^{-1}$ and RMS errors were 0.037 $m\cdot s^{-1}$, 0.033 $m\cdot s^{-1}$, 0.039 $m\cdot s^{-1}$ and 0.054 $m\cdot s^{-1}$ for four paths, respectively.

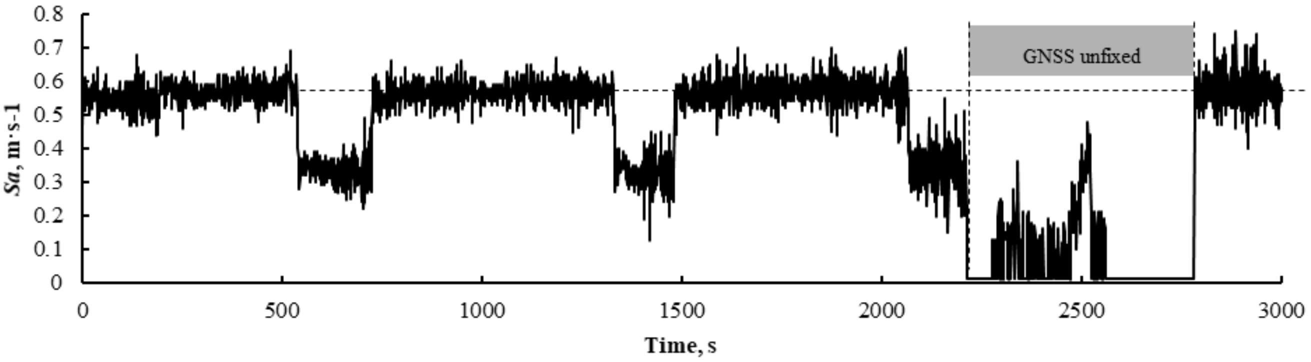
Results in autonomous navigation indicated that the newly developed test platform worked accurately and stably in automatic steering and speed control.



(a) Navigation map (in red) and actual trajectory (in blue)



(b) Lateral error



(c) Moving speed

Figure 9 Autonomous navigation tests

4. Conclusions

A general-purpose test platform was developed at a low cost in terms of its automatic steering, speed control and CAN bus communication network based on an electric vehicle chassis. Experiments were designed to verify accuracy and stability in path following by introducing the autonomous navigation system that was established using fusion of RTK-GNSS and IMU by Shandong University of Technology. Results showed that maximum RMS values for the lateral error and moving speed were 2.6 cm and 0.054 $m \cdot s^{-1}$, respectively, with the desired moving speed as 0.55$m \cdot s^{-1}$. It was indicated that the newly developed general-purpose test platform met requirements of autonomous navigation tests for basic functions including automatic steering and speed control. Future work will focus on integrating more autonomous navigation systems based on navigation sensors besides RTK-GNSS and IMU under both structured and unstructured environments.

Acknowledgements

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References

[1] Hossein Mousazadeh. A technical review on navigation systems of agricultural autonomous off-road vehicles. Journal of Terramechanics, 2013; 50(3): 211-232.

[2] Li Shichao, Cao Ruyue, Ji Yuhan, Xu Hongzhen, Zhang Man, Li Han. Performance analysis and comparison of different types of steering wheel turning control motors in automatic navigation system. Transaction of the Chinese Society for Agricultural Machinery, 2019; 50(S1): 40-49. (in Chinese)

[3] Zhang Zhigang, Wang Guimin, Luo Xiwen, He Jie, Wang Jin, Wang Hui. Detection method of steering wheel angle for automatic tractor driving. Transaction of the Chinese Society for Agricultural Machinery, 2019; 50(03): 352-357. (in Chinese)

[4] Liangliang Yang, Noboru Noguchi, Ryosuke Takai. Development and application of a wheel-type robot tractor. Engineering in Agriculture, Environment and Food, 2016; 9(2): 131-140.

[5] Xiang Yin, Yanxin Wang, Yulong Chen, Chengqian Jin, Juan Du. Development of autonomous navigation controller for agricultural vehicles. International Journal of Agricultural and Biological Engineering, 2020; 13(4): 70-76.

[6] Zeng Hongwei, Lei Junbo, Tao Jianfeng, Zhang Wei, Liu Chengliang. Navigation line extraction method for combine harvester under low contrast conditions. Transactions of the Chinese Society of Agricultural Engineering, 2020; 36(4):18-25. (in Chinese)

[7] Zhao Zuoxi, Luo Yangfan, Ma Kunpeng, Song Junwen, Tan Ting, Meng Shaoyang. Satellite navigation operating accuracy testing method of rice transplanter based on total station. Transaction of the Chinese Society for Agricultural Machinery, 2019; 50(S1): 50-56. (in Chinese)

[8] Jongmin Choi, Xiang Yin, Liangliang Yang, Noboru Noguchi. Development of a laser scanner-based navigation system for a combine harvester. Engineering in Agriculture, Environment and Food, 2014; 7(1): 7-13.

[9] Ryosuke Takai, Liangliang Yang, Noboru Noguchi. Development of a crawler-type robot tractor using RTK-GPS and IMU. Engineering in Agriculture, Environment and Food, 2014; 7(4): 143-147.

[10] Xiang Yin, Noboru Noguchi. Development and

evaluation of a general-purpose electric off-road robot based on agricultural navigation. International Journal of Agricultural and Biological Engineering, 2014; 7(5): 14-21.

[11] Pawin Thanpattranon, Tofael Ahamed, Tomohiro Takigawa. Navigation of autonomous tractor for orchards and plantations using a laser range finder: Automatic control of trailer position with tractor. Biosystems Engineering, 2016; 147: 90-103.

[12] Santosh A. Hiremath, Gerie W.A.M. van der Heijden, Frits K. van Evert, Alfred Stein, Cajo J.F. ter Braak. Laser range finder model for autonomous navigation of a robot in a maize field using a particle filter. Computers and Electronics in Agriculture, 2014; 100: 41-50.

[13] Jinlin Xue, Lei Zhang, Tony E. Grift. Variable field-of-view machine vision based row guidance of an agricultural robot. Computers and Electronics in Agriculture, 2012; 84: 85-91.

[14] Wonjae Cho, Michihisa Iida, Masahiko Suguri, Ryohei Masuda, Hiroki Kurita. Vision-based uncut crop edge detection for automated guidance of head-feeding combine. Engineering in Agriculture, Environment and Food, 2014a; 7(2): 97-102.

[15] J. Backman, T. Oksanen, A. Visala. Navigation system for agricultural machines: Nonlinear Model Predictive path tracking. Computers and Electronics in Agriculture, 2012; 82: 32-43.

[16] Noboru Noguchi, John F. Reid, Qin Zhang, Jeffrey D. Will, Kazunobu Ishii. Development of robot tractor based on RTK-GPS and gyroscope. In: Proceedings of the 2001 ASAE Annual International Meeting, 2001, ASAE Paper 01-1195.

[17] Oscar C. Barawid Jr., Akira Mizushima, Kazunobu Ishii, Noboru Noguchi. Development of an autonomous navigation system using a two-dimensional laser scanner in an orchard application. Biosystems Engineering, 2007; 96(2):139-149.

[18] Wonjae Cho, Michihisa Iida, Masahiko Suguri, Ryohei Masuda, Hiroki Kurita. Using multiple sensors to detect uncut crop edges for autonomous guidance systems of head-feeding combine harvesters. Engineering in Agriculture, Environment and Food, 2014b; 7(3): 115-121.

[19] Chi Zhang, Noboru Noguchi, Liangliang Yang. Leader–follower system using two robot tractors to improve work efficiency. Computers and Electronics in Agriculture, 2016; 121: 269-281.

[20] Noboru Noguchi, Jeff Will, John Reid, Qin Zhang. Development of a master-slave robot system for farm operations. Computers and Electronics in Agriculture, 2004; 44: 1-19.