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Development of a Human-driven tractor following a Robot System

Chi Zhang. Liangliang Yang, Noboru Noguchi*

**Laboratory of Vehicle Robotics, Graduate School of Agriculture, Hokkaido University, Japan. (E-mail: noguchi@bpe.agr.hokudai.ac.jp)*

Abstract: Automated agricultural equipment such as a robot tractor has been developed to solve the problem of agriculture labor force shortage. A human-driven tractor following a robot system is useful for saving time on a large-scale farm. In this kind of system, a robot tractor does farm work while a human-driven tractor is following and doing a different operation. The human operator can control the robot through a controller. To monitor work conditions of the leading robot tractor, four cameras are mounted on the robot tractor, and images from the cameras are sent to the human-driven tractor through a video transmission system. The human operator can check the surroundings of the robot from a monitor. Also, a laser scanner is mounted in the front of the robot for safety. The results of an experiment using the system showed that the precision of the robot tractor, which had an RMS error of about 0.03 m, was better than that of an experienced tractor operator, for which the RMS error was about 0.04 m, while the range of lateral errors of the human-driven tractor improved from 0.25 m to 0.20 m by following the robot.

Keywords: following system, robot tractor, human-driven tractor, laser scanner

1. INTRODUCTION

Increased and sustained agricultural productivity is needed to meet the globally increasing demands for food and energy. The development of new agricultural machinery will enable reduction in the cost of food production and provision of a stable food supply. Over the past two decades, the age of the overall agricultural labour force has been increasing, while the total number of farmers has been decreasing. According to the Japanese Ministry of Agriculture, Forestry and Fisheries, the agricultural workforce in 2010 was 2.6 million people, a reduction of 2.2 million (45.6 percent) from the workforce in 1990. Also, the average age of the agricultural workforce increased from 59.1 years (1995) to 65.8 years (2010). Although agricultural labour is decreasing and aging, agricultural acreage per household in Japan increased from 1.83 ha (in 2007) to 2.07 ha (in 2012). In Hokkaido, the agricultural acreage per household has increased by 15.5 percent in the past 6 years. In 2012, the average agricultural acreage per household in Hokkaido reached 22.34 ha. Automation of agricultural machinery is considered to be one of the most effective ways for improving productivity and quality of various field operations (Noguchi et al., 2004). Noguchi et al. (2001) developed a field robot based on sensors including RTK-GPS and an inertial measurement unit (IMU). In their study, the robot could do farm work with an error of only 0.05 m. Such a system can perform farm work more precisely than an experienced human under straight line conditions.

However, when a robot is used in an open field, a monitoring system is required to ensure safety (Noguchi et al., 2000). At least one worker is needed to monitor the robot's operation, which is equal in efficiency to a single human drives a tractor (Noguchi et al., 2002), only to reduce the working strength. With improvements in robot technology and social needs, researchers have become interested in a multi-robot system or a human-driven tractor following a robot tractor system. Noguchi et al. (2004) developed a master-slave robot system to conduct farm work.

The objective of this study was to develop a robot tractor that can perform farm work with a human-driven tractor. When a robot tractor conducts an operation such as tillage, a human-driven tractor just follow the robot to do proceeding work at the same time. By following the robot, human driver can see the status of robot tractor and improve driving accuracy. In order to accomplish this objective, a remote controller for the robot tractor was first developed. Then a communication system that can receive a command from the remote controller and send a command to the robot tractor was developed. Finally, monitor system was used to assist human drive.

The newly developed following system has several advantages. Firstly, during the rainy season, farmers must finish farm work in a limited time; otherwise, it will lead to some disadvantages in crop yields. The following system can reduce work time to improve such problems. Secondly, compared with a single robot, the following system, in which a single human operator can control two tractors at the same time, reduces not only working time but also working strength. Moreover, the following system helps in weed control. Weeds generally begin to grow after tillage and have an adverse impact on crops. In Hokkaido area, the average farm was 22.34 ha, suppose the velocity of tractor was 1.5 m/s, thus each operation will take at least 18 h. However, the following system can perform tillage and planting at the same time, thus reducing the growth period between weeds and crop. Finally, compared with a large robot tractor, the following system gain advantages over soil compaction, the following system consisting of two middle-sized tractors reduces damage to the crop and ground.

2. Experimental Equipment and Method

2.1 Equipment

2.1.1 Robot tractor

Fig. 1 shows the architecture model for the robot tractor. The tractor used in this study was a Yanmar EG83, and the specifications of the robot include steering control, a switch for forward and backward movements, easy-change transmission, a switch for power take off, hitch functions, engine speed set, engine stop and brake. A computer was used to communicate with the tractor through a CAN bus. An RTK-GPS with an embedded IMU (AGI-3, Topcon Co., Ltd, Japan) was mounted on the top of the tractor, and the robot tractor was equipped with a wireless video transmitter (COSMOWAVE Co., Ltd, Japan), 4CH QUAD Processor (Shenzhen Suntex Electronics Co., Ltd, China), four cameras (DW INC Co., Ltd, Japan), a laser scanner (HOKUYO AUTOMATIC CO.,LTD, Japan) and a Bluetooth. Three markers to assist the human operator were attached to the equipment on the robot tractor. One of the markers was in the centre of the equipment, and the other two were aligned with the wheels of the robot tractor. In this case, human can drive the following tractor to follow the mark created by markers.

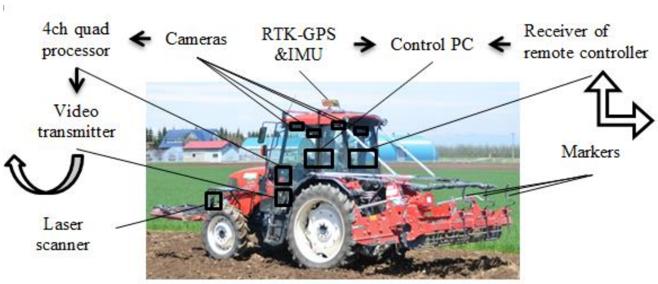


Fig.1 Equipment for robot tractor

Considering potential collisions during agricultural operations, an obstacle avoidance system is an important component in robotic applications. The remote video transmission system included four cameras, video transmitter/receiver, 4ch quad processor and a monitor. Four cameras were attached to the front and back of the robot tractor on both left and right sides. The quad processor splits the screen into 4 rectangles to show images from each of the four cameras and then send the images through a wireless video transmitter. After receiving the images through the wireless video receiver mounted on the manual tractor, the images are displayed on a monitor. Thus, the human operator can see all four sides of the robot tractor, enabling decisions to be made in emergency situations. Fig. 2 shows a picture of the video transmission system. If somebody comes near the robot tractor, the human operator can stop the robot to avoid a collision. The human operator can also see the status of equipment through the rear camera.

Fig.2 Wireless video transmission system

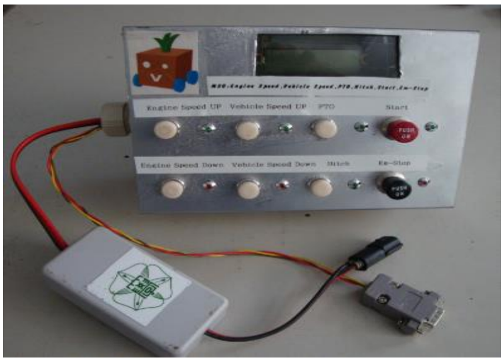
A laser scanner was mounted in the front of the robot tractor. Once an object was detected in the predetermined zone, it will send message to the robot to stop. The coordinates of laser scanner is defined in polar coordinates system. The coordinate of an object was transformed from laser coordinates ($\rho, \boldsymbol{\theta}$ polar coordinates) to vehicle coordinates (x, y Cartesian coordinates), as in (1).

$$x=\rho \times cos\theta \quad (1)$$
$$y=\rho \times sin\boldsymbol{\theta}$$

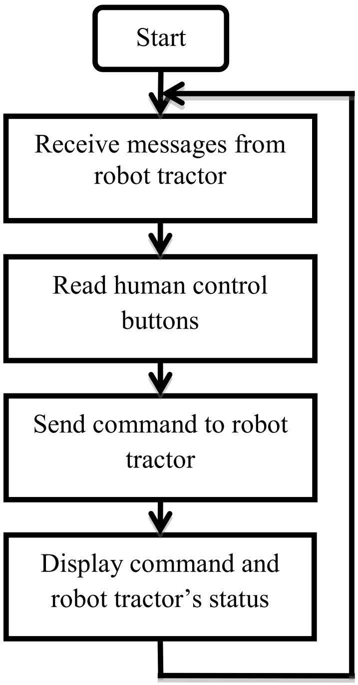
2.1.2 Human-driven tractor

A remote controller and a monitor are used to assist the human operator. The following system includes two parts: a remote controller and a remote video transmission system.

Fig. 3 (a) shows a picture of the remote controller and Fig. 3 (b) shows a flowchart of the algorithm of the remote controller. The controller sends a command to the robot tractor and receives feedback messages from the robot tractor. The human operator can change the parameters of a command by using the relevant buttons. The monitor displays the command and current robot tractor's response status, which helps the human operator to modify the tractor's command parameters.



(a) Picture of remote controller



(b) Flowchart of the algorithm of remote controller

Fig.3 Remote controller

In this study, the remote controller was developed based on Windows API, and a windows platform was needed. The human operator can control engine speed, vehicle speed, PTO on/off, hitch up/down and stop. The steering was controlled by the robot itself without human involvement.

Communication software was developed to communicate with the remote controller, and exchange messages with the robot tractor's software. Two Bluetooth devices were used as wireless communication tools. The devices were connected to the remote controller through RS232. The effective working distance of the communication was 150 m.

2.2 Method

2.2.1 Path plan

The width of the equipment on the robot tractor is the same as that on the human-driven tractor, and the overlap of the path is zero. If the robot tractor goes to the neighbour path, there will be a risk of collision of the equipment. To avoid collision of the equipment on the tractors, the sequence of the path order was disordered, with at least one path being skipped from last path to the current path. For example, in a six-path map, as shown in Fig. 4, the red numbers are the work sequence of the robot tractor, and the order is 1→4→2→5→3→6.

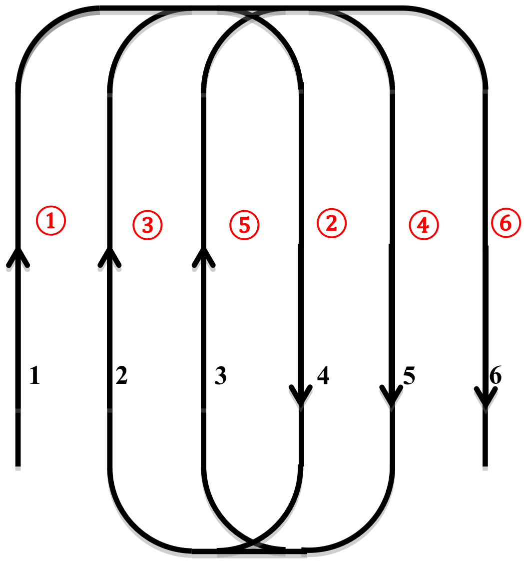


Fig.4 Path order of six paths

2.2.2 Headland turning method

A U-turning method was used in this study, as shown in Fig. 5. The turning steps are as follows.

Step 1: The robot goes straight forward from A to B and then turns at the maximum steering angle to point C.

Step 2: The robot calculates the distance between the current path and the next path, which is w, and then decides the distance between point C and point D, which is w-$2r$, where, r is the minimum turning radius of the robot tractor. If w is less than $2r$, the robot will go backward to ensure a turning radius.

Step 3: The tractor turns to the next path from point D, and turning finishes at point F.

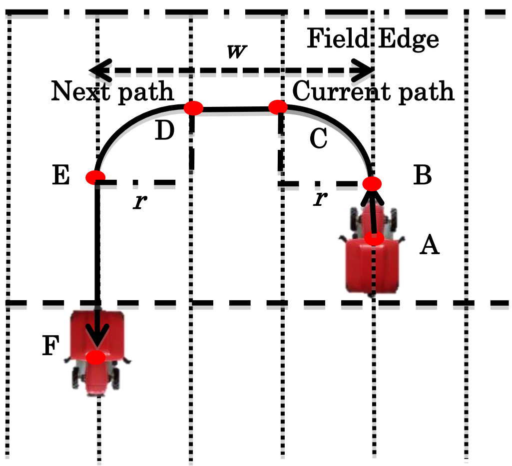


Fig.5 U-turning method

3. Experimental Results and Discussion

A field experiment was conducted on a farm in Hokkaido University, Japan. The experiment was conducted to check the response of the following system. In the experiment, tillage was performed by the robot tractor and planting was performed by the human-driven tractor, as shown in Fig. 6. The robot carried a power harrow, and three markers were mounted on the power harrow. The markers were aligned with the left wheels, centre of the tractor and the right wheels, respectively. The human-driven tractor was equipped with a planter, which can do seeding and fertilizing. The widths of the power harrow and planter were the same, and the working width was 2.3 m. The overlap of the two paths was zero. And the robot cannot get into the neighbour path because of conflict between leader's equipment and follower's equipment on headland and working path.

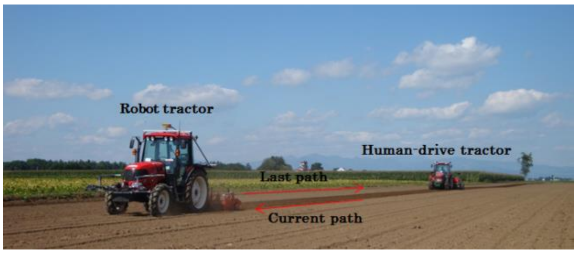


Fig.6 Working path of associating system

3.1 Performance of the tractors

For the experiment, we made a six-path map for the robot tractor. The sequence of the ten paths was reordered as 1→4→2→5→3→6. Fig. 7 shows the map and trajectory of the robot tractor. We used lateral error, which is the distance between a predetermined path and current position of the robot tractor, to evaluate the performance of the robot tractor and the human-driven tractor. Fig. 8 shows the lateral error of the robot tractor.

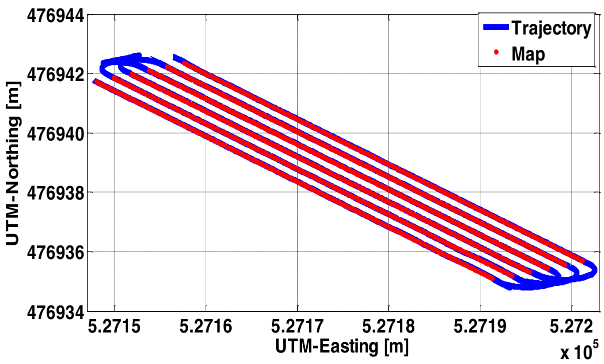
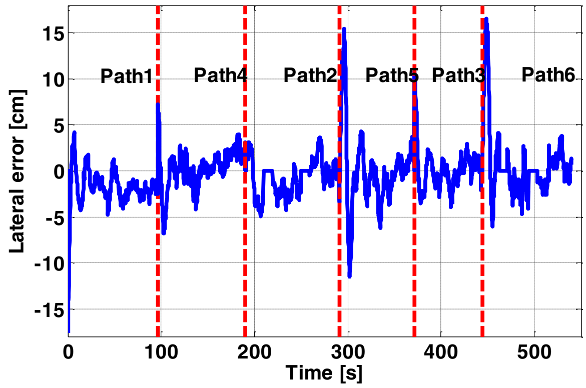
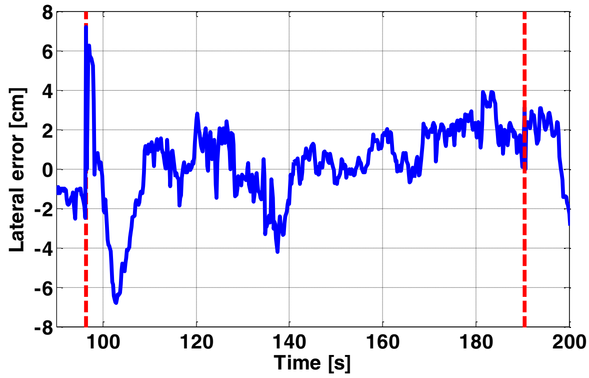


Fig.7 Map and trajectory of robot tractor



(a) Lateral error of 6 paths



(b) Zoom in path4

Fig.8 Lateral error of robot tractor

The maximum error was 0.16 m, and the minimum error was -0.17 m. The average RMS of the lateral error of all 6 paths was 0.03 m. The average of absolute value of lateral error was 0.02 m, and the average lateral error was -0.003 m, which is an acceptable value.

Fig. 9 shows turning accuracy of the robot tractor. Turning accuracy is lateral error of the beginning of the working path, from point E to point F, as shown in Fig. 5. The maximum, minimum, average and RMS of the turning lateral error were 0.12 m, -0.14 m, 0.01 m and 0.08 m, respectively. The average of absolute value of lateral error was 0.08 m. At the end of the turning part, the average lateral error of all 6 paths was -0.01 m. The turning accuracy was 0.06 m lower than that of the working part, but it is also an acceptable value.

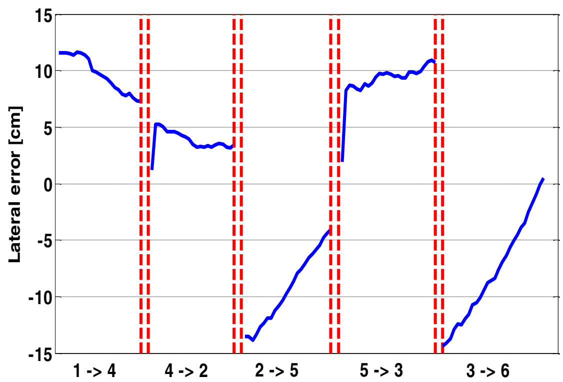
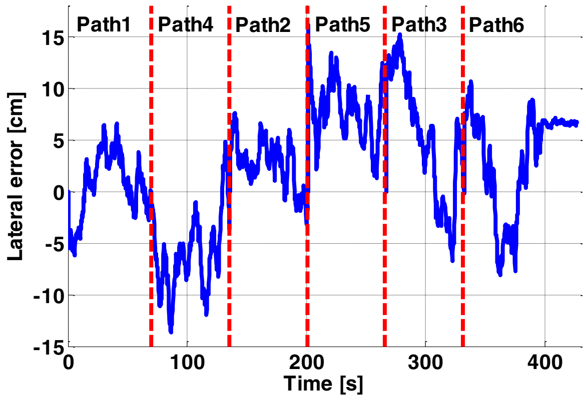
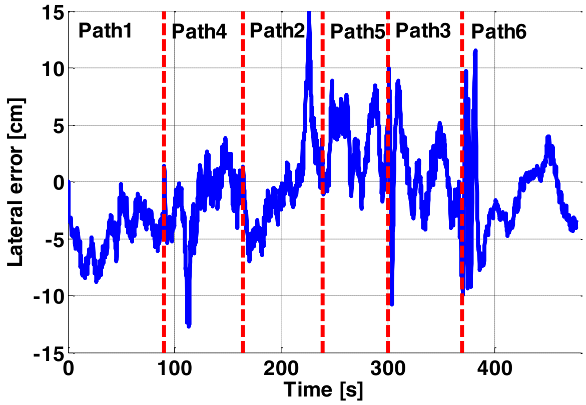


Fig.9 Turning accuracy

Fig. 10 shows the effectiveness of the newly developed following system in terms of accuracy of the human-driven tractor. As described above, markers were mounted on the robot tractor, and the human operator followed the track generated by the markers. The average velocity of human-drive alone and human drive following robot was different. The velocity of human-drive alone was 0.9 m/s, that 0.1 m/s faster than that of following the robot. Fig. 10 (a) shows the lateral error of human-driven tractor without following the robot. The maximum and average of the lateral error of all 6 paths were 0.10 m and 0.02 m, respectively. And the average of absolute value of lateral error was 0.05 m. Fig. 10 (b) shows the performance of the human-driven tractor following the robot tractor. The maximum and average of the lateral error of all 6 paths were 0.08 m and -0.007 m, respectively. And the average of absolute value of lateral error was 0.03 m. By following the robot tractor, the precision of the human-driven tractor improved by forty percent, from 0.05 m to 0.03 m.



(a) Human-drive alone



(b) Human-drive following robot

Fig.10 Lateral error comparison of human-driven tractor

The human driver had over 30 years of driving experience. The results showed that the range of lateral errors of the human-driven tractor improved by twenty percent, from 0.25 m to 0.20 m, by following a leading robot. Also, it will reduce human's working strength by following the robot tractor.

3.2 Performance of the remote controller

In this study, the newly developed following system allowed the operator on the following tractor to control the engine speed and velocity of the robot tractor while the robot was tracking a straight line. Fig. 11 shows the engine speed in response to the command from the human operator. The engine speed was used to check the current situation of the robot tractor. If the speed of the robot and PTO rotation rate were so high that the engine cannot satisfy, the human driver can either decrease the velocity or increase the engine speed.

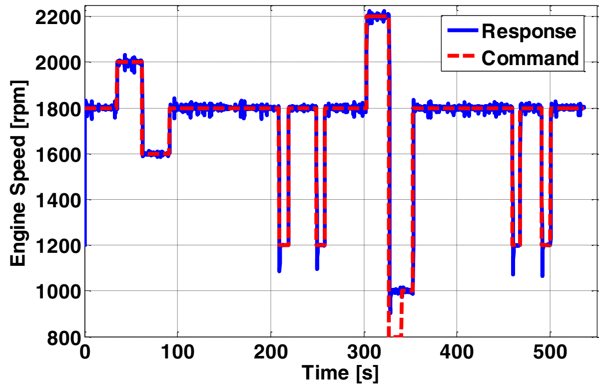
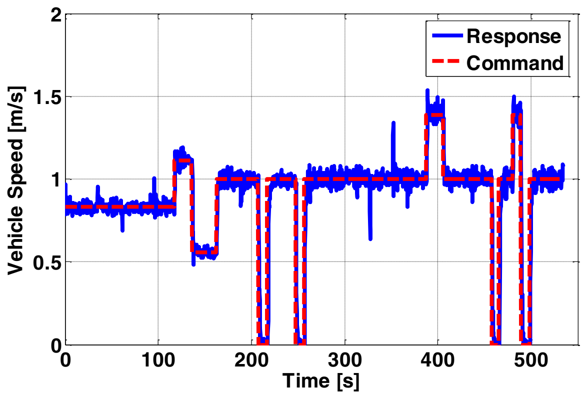
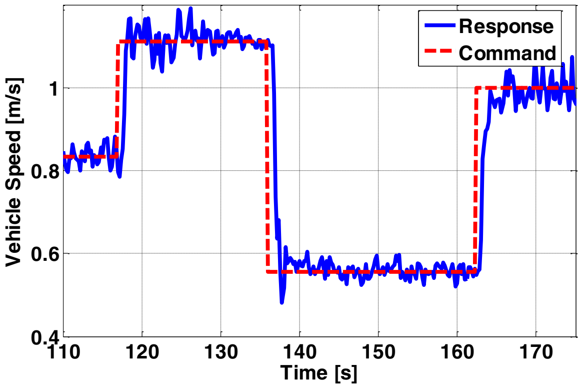


Fig.11 Engine speed response of robot tractor

Fig. 12 shows vehicle speed in response to the command from the human driver. As shown in Fig. 12 (b), the time delay was about 1.8 s when the velocity was changed. The time delay includes delay of remote controller, delay of communication software, delay of robot tractor's software and delay of tractor's ECU. From the logging data, the delay of remote controller and communication software can be calculated. The delay of remote controller was 0.2s, and delay of communication software was 0.3s. The robot tractor's delay was 1.3s. In this experiment, the velocity of the robot tractor was 0.8 m/s, which means it continues work about 0.72 m after the human operator has pressed the stop button. It is concluded that this distance is acceptable for stopping the robot tractor in an emergency situation. In addition, restarting the robot took 2.6 s. A function was added to the robot system by which the robot checks that one second has passed to ensure safety before it restarts after stopping.



(a) Vehicle speed response of robot tractor



(b) Zoom in area of (a)

Fig.12 Vehicle speed response of robot tractor

4. Conclusions

In this study, a robot tractor following with a human-driven tractor was developed to improve agricultural work efficiency and safety for robot operations.

A robot tractor and a human-driven tractor were used in this study. The average lateral error was less than 0.03 m. The human operator just followed a marked line created by the leading robot tractor. The human operator used a controller to control the robot, and equipment for observing the robot's surroundings by a wireless video transmission system was installed. One human operator can maneuver two tractors, and the efficiency of farm work is thus improved. Also, by following the robot tractor, the human operator can drive on a predetermined path more accurately, from 0.06 m to 0.03 m. The range of the human operator's lateral errors improved from 0.25 m to 0.20 m. The accuracy of human-driven tractor was high enough for agriculture work.

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