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A Vision-Aided Tractor Guidance Simulator

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ABSTRACT

To achieve a reasonable level of precision in tractor-based field operations, a tractor operator has to guide accurately, monitor and control both the tractor and the attached implement. Since guidance is the most time consuming task among the others, researchers have attempted to automate the guidance task. However, the use of automatic guidance and control in agricultural applications is not always appropriate. Transportation of the vehicle on a public road is an example of this. Some researchers, therefore have focused on Vision-Aided methods to give some guidance aid to the driver rather than on eliminating the driver. To investigate the accuracy of such methods, a Vision-Aided tractor guidance belt-type simulator was developed. An experimental prototype of the simulator was constructed. To evaluate the prototype, a completely randomized factorial experiment was conducted with forward speed, heading angle, and camera tilt angle being the major factors under investigation. The simulator performed satisfactorily at 5 and 7km/h and mean deviations of 1.14 and 2.31cm were obtained respectively.

Keywords: Guidance, Simulator, Tractor, Vision.

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INTRODUCTION

Almost all field machines used in major agricultural crop production operations (i.e., seed bed preparation, planting, weeding, and harvesting) have three needs in common; they must be guided along a predetermined path and their forward speed and depth (or height) of work must be controlled. Guidance of agricultural vehicles is the most difficult task in modern agricultural practices. Frequently, the guidance task requires so much of the operator's time and attention that he or she cannot respond in order to implement control (i.e., adjustment) needs caused by changing field conditions. It has been calculated that a lot of time is taken up by repetitive low speed work on the land (Nix, 1989). Elimination of a driver from such operations as drilling, spraying and cultivating may improve productivity dramatically and reduce fatigue and the risks from the potentially hazardous tasks, orchard spraying for example.

Unfortunately, there are some situations that make use of automatic guidance and control in agricultural applications questionable, one being transportation of the vehicle to the field on a public road for which a driver will be required (Tillet, 1991). Automatic steering of tractors dates back to the 1960's and in one study mechanical sensor was used as a crop row-sensing device to steer tractor in corn mechanical cultivation (Hunt *et al*., 1960). It has been suggested that 5cm is the maximum tolerable course-tracking error for many field operations (Choi *et al*., 1989). Tillet (1991) classified guidance systems as mechanical, optical, radio navigation, ultrasonic and leader cable systems. Most of these systems use the same guidance parameters, one being the heading angle. In an attempt to study the principle of substituting information for energy in agri-

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culture, Chancellor (1981) pointed out that the efficiency of a technology depends upon its ability to use information to guide and time the application resources. Many suitable applications for automatic guidance exist in today's agriculture. Existing concepts and techniques can make such systems a reality but it seems that the missing link, which is a suitable spatial position-sensing device for accurately locating the machine in the fields, is still there (Smith *et al*., 1981).

Brown *et al.* (1990) showed that video cameras and computers are theoretically accurate and fast enough to provide steering information for a row-crop operation. A vision system provides information not available from the other guidance sensors. This information has a value within the context of the site-specific crop management. Thus the flexibility of the vision system makes it a valuable sensor for agricultural process automation (Pinto *et al*., 2000). Most researchers have attempted to develop automated guidance systems using the operating principle described above, but development of guidance-aid system that provides guidance information to the driver rather than replacing the driver has received little attention (Tang *et al*., 1999).

To avoid hazardous conditions and to provide an educational base for the operator, researchers have proposed the development of a Tractor Driving Simulator (TDS) (Wilkerson *et al*., 1993) to study guidance systems. The complexity of the simulators varies from the operator station controls to belt simulators in conjunction with scale models steered by microcomputer (Smith *et al*., 1981), steering dynamic simulators (Wu *et al*., 1998) and vehicle simulators controlled by neural networks (Noguchi *et al*., 1994).

Almost all previous studies in the area of automatic guidance systems for tractors dealt with teaching tractor operators steering performance and steering dynamics rather than the guidance aid. Moreover most of these studies used some kind of scaled model.

The objectives of this research were as follows:

1. To prepare a preliminary conceptual design for a TDS using a video camera as a guidance aid,
2. To built a prototype TDS,
3. To conduct preliminary experiments for determining the feasibility of using the simulator to simulate the task of precisely positioning a tractor with respect to a line representing a row of plants

Layout of the simulator components is given in Figure 1. The proposed control system shown in Figure 4 is based on the following principle. The simulator is basically of a belt type in that the belt is run by variable speed inverter-driven motor with its speed controlled by a Belt Speed Control Potentiometer (BSCP) linked to the inverter and actuated by a Speed Control Pedal (SCP). This configuration simulates speed control. To simulate different path patterns found in typical fields, a pen that is a Dry-Erase marker in contact with the belt passing over the drive pulley draws a line on the belt to represent a path within a field to be followed. Lateral motion enables the marker to draw different patterns of lines according to different heading angles to be followed. An eraser removes the line while the belt is passing over the driven pulley so that only one line (row) is present on the belt at a time. A driver, who is monitoring the path through an LCD (Liquid Crystal Display) monitor, searches for the path by rotating the camera mounted on a carriage. The amount and the sign of the angle of rotation determine the direction of travel and the amount of speed for carriage respectively. This causes the carriage to move in the appropriate direction with a specific speed ratio corresponding to belt speed.

MATERIALS AND METHODS

The proposed simulator consists of two separate sections, namely the belt drive and camera drive sections respectively. Figure 1 shows the simplified layout of the simulator. A 2.6m×2.2m×0.7m frame for the belt drive

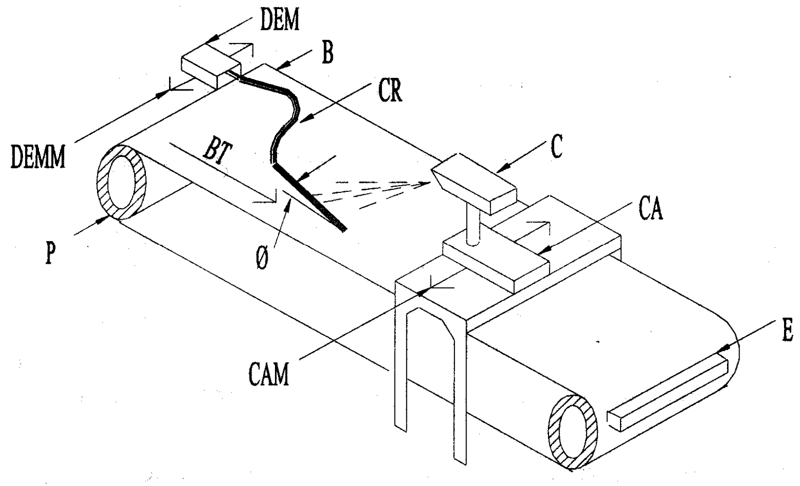

Figure 1. Simplified tractor guidance simulator layout, (B, BT, C, CA, CAM, CR, DEM, DEMM, E, and P are belt, belt travel direction, camera, carriage, carriage move, crop row, dry-erase marker, dry-erase marker move, eraser and pulley respectively).

section was built using 50.8mm×50.8mm angle iron. Two pieces of 178 mm diameter steel tubing were used to build flat belt pulleys. Each pulley has stub shafts welded on either end mounted in pillow block bearings bolted on to the frame. Provisions were made for centre distance adjustments between the two pulleys. The drive pulley was powered by a type 16-0071-05, 120 V permanent magnetic field 1500 r/min DC servomotor (Gettys manufacturing Co. Inc.) exerting a torque of 12 Nm. As the input voltage into the motor varied between 0 and 120 V the speed of the motor varied between 0 and 1500 r/min. A double step speed reduction chain (½ inch pitch, No. 40) drive with an overall ratio of 1: 8 was chosen. This allowed the motor to be run at its optimum torque range. With this design, the belt could be run at the typical speeds of modern agricultural field operations (i.e., 2, 5, and 7 km/h). To simulate the forward speed of a tractor a commercially available 4.8m long and 2m wide endless (seamless) conveyor belt (esbelt, type Clina C 07UF) was mounted on the pulleys. The top of this belt is covered by PU (Polyurethane), white in colour and 0.30mm thick and has smooth surface. The bottom of the belt which is covered by PU also, has natural colour and an impregnated surface 0.10mm thick. It is food quality material that resists oils, animal and vegetal greases and abrasion. Its temperature range is between –10°C to +100 °C. The fabric used in belt construction is one ply rigid weft and the belt thickness is 0.80mm and weighs 0.90 kg/m². At 20 ºC it could work on a flat pulley as small as 10mm in diameter. The breaking load of the belt is 60 N/mm width and at 1% elongation its working load is 7 N/mm. The belt has very smooth white surface on which Dry-Erase marker could be used while the bottom surface is rough enough to prevent slippage between belt and pulley. A 2.4m×0.4m×1.0m frame was built for the camera drive section using 50.8×50.8 mm angle iron. Two pieces of 2.4m long precision ground round guide bars were attached along the top of the cross-angle bars so that the carriage holding the camera assembly could slide in a direction perpendicular to the direction of belt travel. Four partial bearings with PTFE (Polytetrafluoroethylene)

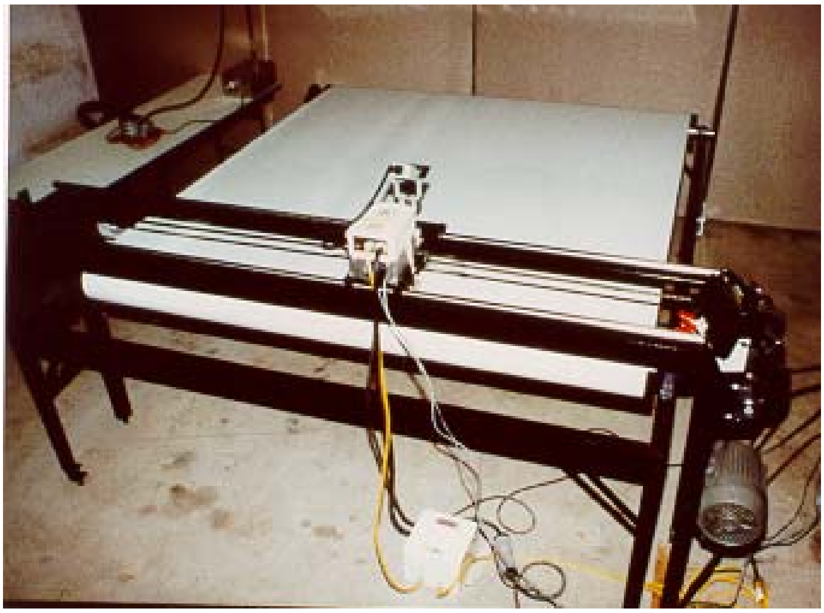

Figure 2. An experimental prototype of the simulator.

lining were used, one on each corner of the carriage, to mount the carriage on the guide bars. The carriage was activated by a Toshiba 1725 r/min, 0.745 kW 3 phase inverter-controlled AC induction motor (EPACT-HIGH EFFICIENCY, Model No. B0014FLF2UMW01) through roller chains (3/8 inch pitch, No. 35) attached to either sides of the carriage (Figure 2). To overcome low speed limitations associated with this kind of drive, a double step speed reduction chain-drive was again used with an overall speed ratio of 1: 8.

The CAMTRAK Electronic Field Position Indicator (Excel Innovations Inc., Martensville, SK) was used as a guidance aid. This system consists of a Y3 colour CCD camera (model no. OPSCBC6) with a 15° field of view in the longitudinal direction and an 18° field of view in the lateral direction and a TFT, LCD active matrix monitor with screen size of 130mm wide by 95mm high. The camera was mounted on top of a vertical rod 600mm above the belt surface in such a way that it could be rotated around a horizontal axis to set a camera tilt angle. It was also possible to rotate the camera around its vertical axis so that the heading angle of the camera could vary. The bottom end of the vertical rod mentioned above is extended underneath the carriage in such a way that it could hold a Dry-Erase marker in contact with the belt surface. This marker drew a line on the belt as it passed by. To follow both positive and negative heading angles, the carriage's direction of travel had to be changed according to the sign of the heading angle. To detect the sign of the heading angle, a 20 mm high collar was mounted on the camera-holding rod and its cylindrical wall surface was divided into two equal black and white regions as seen in Figure 3, so that a photoelectric sensor in proximity detected the borderline as the camera was rotated and the sign of the heading angle was changed.

The CAMTRAK Electronic Field Position Indicator was used in a manner described by Tang and Mann (2000) in which a small pointer had been attached to the bottom portion of the LCD screen. The length of the pointer was one-third of the height of the screen and it was aligned vertically with the center-line of the screen. During simulation,

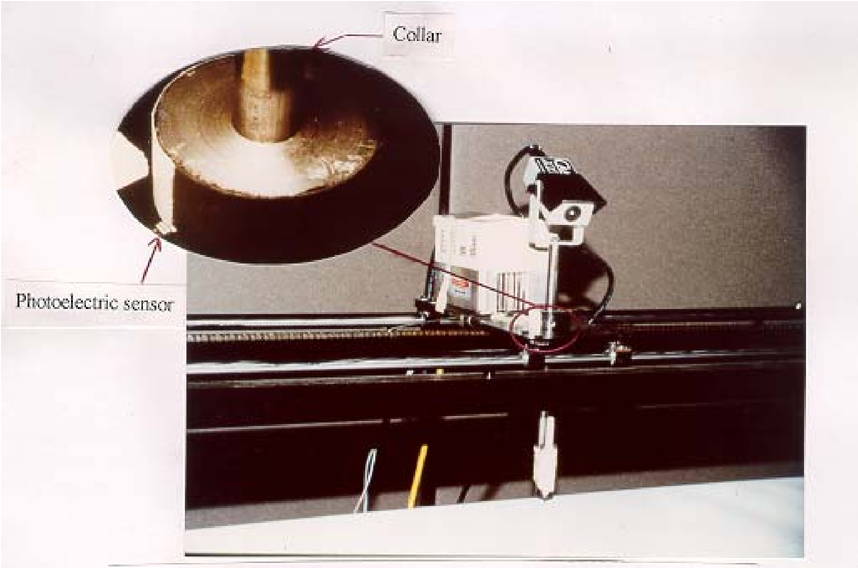

Figure 3. The collar and photoelectric sensor arrangement for heading angle sign detection.

the objective is to align the image of the line drawn on the belt with the pointer by rotating the camera about its vertical axis. Simultaneously, the lateral speed of the carriage carrying the camera is adjusted according to the heading angle. The greater the heading angle, the higher the lateral speed of the carriage. This capability of the simulator enabled us to simulate forward travel guidance of a tractor. The relationship between belt speed, which represents the forward speed of a tractor, and carriage lateral speed, could be written as follows:

$$dV_c = dV_b \tan\varnothing \qquad (1)$$

where V_c, V_b and $\varnothing$ are the carriage lateral speed (m/s), belt speed (m/s) and heading angle, respectively.

To examine the feasibility of the concept, a Completely Randomized Factorial Experiment was conducted during which the performance of the simulator was evaluated. Three factors were investigated: speed (2, 5, and 7 km/h), heading-angle (2.5º and 4.5º) and camera tilt-angle (30º and 45º). Deviation from the proposed line on the belt (representing a path in the field) was considered as a response variable. Two replicates were done for all twelve variable combinations. Before each test, a line with a determined heading angle was drawn on the belt using an Expo2 Series No.86000 fine point-marker. To extend a course of run up to 40m, a four-pitch spiral line was drawn on the belt. This was done by lateral motion of the marker in contact with the running belt. The direction of motion for the maker was reversed so that the marker traveled in the reverse direction until another four-pitch spiral line was drawn. This means that almost a half the period of a sinusoidal path with a length of 80m and an amplitude of 0.87m (or 1.5m) was drawn for a heading angle of 2.5º (or 4.5º), respectively, so that the length of each test run was approximately 40m. To record the actual path of steering, a 100mm-long tube was attached to the bottom of the camera holding rod to accommodate a tracing marker. The marker fit loosely inside the tube so that it was in continuous contact with the belt under its own weight. At the beginning of each run, the carriage was positioned in such a way that the tracing marker stood at the beginning of the line. Then the belt drive was started. As soon as the beginning of the line was dis-

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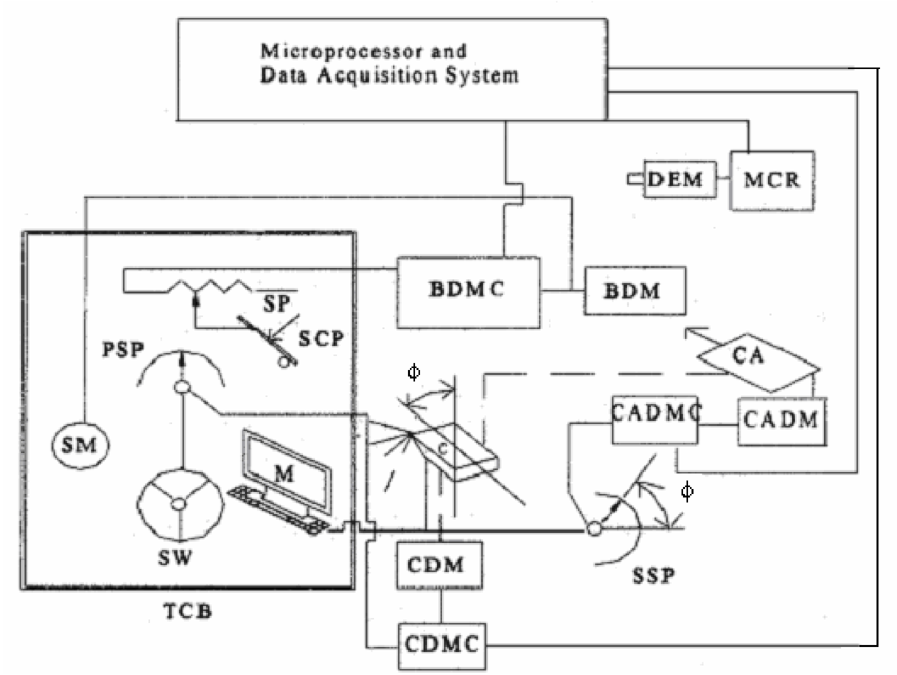

Figure 4. Control system block diagram of the tractor guidance.
Simulator (BDM, BDMC, C, CA, CADM, CADMC, CDM, CDMC, DEM, MCR, M, PSP, SM, SCP, SP, SSP, SW and TCB are belt drive motor, belt drive motor controller, camera, carriage, carriage drive motor, carriage drive motor controller, camera drive motor, camera drive motor controller, dry erase marker, marker controller, monitor, primary steering Potentiometer, speedometer, speed control pedal, belt speed potentiometer, secondary speed potentiometer, steering wheel, tractor cab respectively. Heading angle sign detector is not shown.)

played on the screen of the monitor, the carriage was activated, by the operator, to move laterally to catch up with the line. The inverter's potentiometer was used to control the speed of the carriage while holding the camera's proper heading angle along the line. These co-ordinated actions enabled the operator to align the image of the line with the pointer attached to the LCD screen. As mentioned earlier, a photoelectric sensor was used to detect the sign of the heading angle to change the direction of carriage travel automatically.

The steering action of the carriage drew the actual travel line on the belt. At the end of each test, the system was shut down. The length of test course was marked and numbered at one metre intervals. Due to large start-up errors, the first five metres of each run were ignored. The deviation of 10 randomly selected points out of the 35 points along the remaining 35 metres were recorded. An average deviation was calculated for each run. The data were analyzed by using SAS software through ANOVA and GLM procedures.

To collect the data automatically, a Data Acquisition System (DAS) has been predicted for the next stage of development (Figure 4). The position of DEM and CA (Figure 1) are sensed and compared for deviation evaluation. Data are loaded onto a computer for analysis.

RESULTS

As indicated in Table 1 the effects of speed and camera heading angle on deviation was significant at 1% and 5% levels

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Table 1. The results of SAS ANOVA Procedure (Dependent Variable: Offset, cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	11	12.32085000	1.12007727	2.28	0.0862
Error	12	5.89500000	0.49125000		
Corrected Total	23	18.21585000			

R- Square	CV	Root MSE	Offset Mean
0.676381	41.28968	0.700892	1.697500

Source	DF	Anova SS	Mean Square	F Value	Pr>F
S	2	5.49242500	2.74621250	5.59	0.0192
H	1	1.28806667	1.28806667	2.62	0.1314
C	1	2.28166667	2.28166667	4.64	0.0522
S*H	2	0.84205833	0.42102917	0.86	0.4488
S*C	2	1.25200833	0.62600417	1.27	0.3149
H*C	1	0.01401667	0.01401667	0.03	0.8687
S*H*C	2	1.15060833	0.57530417	1.17	0.3431

S=Speed H=Heading Angle C=Camera Tilt Angle

respectively. The interaction between the factors was negligible. Further analysis by GLM showed that there was a significant difference between repeat tests, the probable reason being lack of skill of the operator to operate the simulator. Table 2 shows the Mean and Standard Deviation for each source of variation. It was observed that the maximum deviation occurred when the heading angle changed sign during the sinusoidal course of run.

The light reflected from the surface of the belt interacted with the image on display but the problem was overcome later when appropriate illumination was provided to the scene. It was also noticed that the longer the marker colour remained on the surface of the belt the more difficult it would be to erase. This situation was even worse in the belt-joint area.

At higher speeds, the belt tended to lift the recorder's marker up so that the trace of the marker was weakened or broken at some points. The belt drive needed some minor adjustments at the end of the 20^{th} test run to prevent it from shifting sideways. This was carried out by realignment of the pulleys. At prolonged low speed operation, the overload trip system of the inverter operated. It was reset according to the manufacturer's recommendations.

DISCUSSION

In general, the vision aided simulator performed satisfactorily. As indicated in Table 2, increasing the speed from 5 to 7km/h increased the deviation. At 2km/h, however, the deviation increase was unexpected since at lower speeds the system had to be controlled better. This can be attributed to the fact that the lowest frequency set for the inverter was 0.5Hz. This means that any further attempt for running the carriage at lower speeds (frequencies lower than 0.5 Hz) would stop the inverter from driving the carriage motor, the natural consequence being

Table 2. The mean offsets and standard deviations, in mm.

Source	Speed			Camera tilt Angle	
	2km/h	5km/h	7km/h	30^o	45^o
Mean (mm)	16.5	11.4	23.1	20.0	13.9
LSD_5%		7.6		6.2	

the stop-and-go behaviour of the carriage and more deviation would result. Moreover, as soon as the carriage stops an operator has to restart the motor by turning the potentiometer of the inverter. By considering the acceleration time of the motor, one can conclude that even further deviation from the proposed path would result. Another reason that might contribute to the deviation is that, after restarting the inverter, it was observed that it was necessary to run the carriage at higher speed than required to compensate for deviation due to delays already mentioned until the line to be followed had been caught up with and the system was stabilized and running smoothly. These problems can be overcome by either using an inverter with higher resolution or by increasing the drive ratio for the carriage. This would allow the carriage to travel at lower speeds while the input frequency to the inverter is well above the lower limit. To eliminate the necessity of adjustments to the pulleys to prevent belt side shifting, a V-belt can be attached under the flat belt to be run in grooves provided on the belt pulleys.

As seen in Table 2, deviation from the path was smaller at a higher camera tilt-angle and this was in agreement with the results obtained by other researchers (Pinto *et al*., 2000). In the present research, since the rotation of the camera as well as speed control for the carriage carrying the camera was carried out manually, the non-linear term of tan (in Equation 1) was compensated for manually. If this project continues towards its further development, as shown in Figure 4, the speed ratio between belt motor and carriage motor can be set through a microprocessor so that the non-linear relationship between belt speed and carriage speed can be dealt with.

Another point that should be mentioned is that, from the view of the camera which is directed along the path, the actual speed would be higher than that of the belt speed which is simulating tractor's forward speed. This is due to the relationship between belt speed and carriage speed. If Vb and Vc represent the linear speed of the belt and carriage respectively, these two vectors are perpendicular and from the view of the camera looking along the path the actual speed would seem to be Va, which is equal to Vb+Vc. This could be dealt with either by decreasing belt speed as the heading angle increases or by making some provisions in speedometer circuitry.

As indicated in Figure 4, a motorized pen can be programmed to draw the different patterns of path found in farms. Having considered a time lag between pen motion and carriage motion, data for deviation can be sampled through a data acquisition system for analysis. The proposed simulator can not only be used for research in the area of vision aided guidance systems but may also be an appropriate tool for those who are interested in studying operator fatigue associated with these systems.

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REFERENCES

1. Brown, N. H., Wilson, J. N., and Wood H. C. 1990. Image Analysis for Vision-based Agricultural Vehicle Guidance. *ASAE Paper No*. **90**-1623. St. Joseph, Mich.: ASAE.
2. Chancellor, W. J. 1981. Substituting Information for Energy in Agriculture. *Trans. ASAE* **24(4)**: 802-807 and 813.
3. Choi, C. H., Erbach, D. C., and Smith, R. J. 1989. Navigational Tractor Guidance System. *ASAE Paper No*. **89**-1026. St. Joseph, Mich.: ASAE.
4. Hunt, D., and Lovely W. G. 1960. Row Cultivation with Manual and Automatic Steering. *ASAE Paper No*. **60**-625. St. Joseph, Mich.: ASAE.
5. Nix, J. 1989. *Farm Management Pocket Book*, 20th edition, Wye College, University of London.
6. Noguchi, N., Ishii, K., and Terao, H. 1994. Autonomous Vehicle by Neural Networks and Genetic Algorithms. *ASAE Paper No*.

94-3054. *1994 International summer meeting*. Kansas city, Missouri.

7. Pinto, F. A. C., Reid, J. F., Zhang Q., and Noguchi, N. 2000. Vehicle Guidance Parameter Determination from Crop Row Images Using Principal Component Analysis. *J. Agric. Eng. Res.*, **75**: 257-264.
8. Smith, L. A., and Schafer, R. L. 1981. Automatic Guidance for Agricultural Machines. *Agric. Eng.*, **62** (9): 12-14.
9. Tang, P., and Mann, D. D. 1999. Evaluation of the CAMTRAK Electronic Field Position Indicator. *ASAE/CSAE Meeting Presentation. Paper No*. MBSK **99**-107. Winnipeg. Canada.
10. Tillet, N. D. 1991. Automatic Guidance Sensors for Agricultural Field Machines: A Review. *J. Agric. Eng. Res.*, **50**: 167-187
11. Wilkerson, J.B., Asbury, B.C., Piather, T.G., and Lown, J. B. 1993. Development of a Tractor-driving Simulator. *ASAE Paper No*. **93-**1615. *1993 International Winter Meeting*. Chicago, IL.
12. Wu, D., Zhang, Q., and Reid, J. F. 1998. Dynamic Simulator of Wheel Type Tractor Steering. *ASAE Paper No*. **98**-3115. *1998 ASAE Annual International Meeting*. Orlando, FL.

شبیه ساز دید- یاري شدة هدایت تراکتور

ح. ر. قاسمزاده و د. د. مان

چکیده

براي دستيابي به سطح قابل قبولي از دقت در عمليات مزرعه‌اي كه اساس آنها استفاده از تراكتور است, راننده تراكتور بايد بطور دقيق تراكتور و ادوات متصل به آن را هدايت و كنترل نمايد. از آنجايي كه عمل هدايت در بين سايرعمليات بيشترين زمان را به خود اختصاص مي‌دهد لذا پژوهشگران تلاش كرده‌اند عمل هدايت را بطور اتوماتيك انجام دهند. ليكن استفاده از هدايت و كنترل اتوماتيك در كاربردهاي كشاورزي هميشه ميسر نيست كه نقل و انتقال وسيله نقليه در جاده‌هاي عمومي مثالي در اين مورد است. بنابراين برخي از پژوهشگران به منظور ياري رساندن به راننده و نه حذف راننده, بر روي روشهاي هدايت ديد- ياري شده متمركز شده‌اند. به منظور بررسي دقت اين روشها يك شبيه‌ساز ديد- ياري شده هدايت تراكتور از نوع تسمه‌اي طراحي و نمونه اوليه آزمايشي آن ساخته شد و براي ارزيابي نمونه اوليه از طرح آزمايش كاملا" تصادفي فاكتوريل استفاده گرديد كه در آن فاكتورهاي اصلي تحت بررسي را سرعت, زاويه پيشروي و زاويه تمايل دوربين تشكيل مي‌دادند. عملكرد شبيه ساز در سرعت‌هاي ۵ و ۷ كيلومتر در ساعت رضايتبخش بوده و ميانگين‌هاي خطا به ترتيب ۱/۱۴ و۲/۳۱ سانتي‌متر بدست آمد.