The Canadian Society for Bioengineering

The Canadian society for engineering in agricultural, food, environmental, and biological systems.

La Société Canadienne de Génie Agroalimentaire et de Bioingénierie

La société canadienne de génie agroalimentaire, de la bioingénierie et de l'environnement

Paper No. 08-154

Investigation of the role of different sensory cues in driving an agricultural vehicle

Davood Karimi, Ph.D. Candidate

Department of Biosystems Engineering, E2-376 EITC, University of Manitoba, Winnipeg, Manitoba, R3T5V6 Canada. Davood_Karimi@umanitoba.ca

Danny D. Mann, Professor

Department of Biosystems Engineering, E2-376 EITC, University of Manitoba, Winnipeg, Manitoba, R3T5V6 Canada. Danny_Mann@umanitoba.ca

Written for presentation at the
CSBE/SCGAB 2008 Annual Conference
Vancouver, British Columbia
July 13 - 16, 2008

Abstract

Driving is an interactive process in which the driver receives the information about the state of the vehicle and its relation to the environment through visual, motion, haptic and auditory cues. Successful and comfortable control of the vehicle requires certain level of sensory cues to be available to the driver. This depends on factors such as the driving task at hand and vehicle dynamics. This paper describes our study on the role of motion cues in the driving of an agricultural vehicle in parallel swathing mode with the help of a lightbar guidance system. Field experiments were performed in which experienced tractor drivers drove a tractor in the parallel swathing mode using a lightbar GPS guidance system. Then, this experiment was repeated in a tractor driving simulator, both with and without motion feedback. Analysis was performed to identify the driver's model as a controller. The results show that experienced tractor drivers do use motion cues in control of the vehicle when driving in parallel swathing mode. When motion cue was provided, drivers chose a more relaxed steering strategy.

Keywords: tractor simulator, steering, tractor operator, human factors, motion cue, GPS lightbar.

INTRODUCTION

Driving simulators are used for research, training, and other purposes such as vehicle and roadway design (Rakauskas et al., 2004; George, 2003). They provide safe and easily controlled experimental conditions in which an experiment can be run many times with the same or arbitrarily modified experimental variables at a much lower cost compared to real road or field tests. However, for driving simulator research to be valuable, the driving simulator must replicate the real world conditions to an acceptable degree. Behavioral validity (or predictive validity) of a simulator describes how close the simulator is to the real world scenario in the way the human driver behaves (Godley, 1999). For a driving simulator to invoke the same behaviors from the driver as in the real world, it should provide him/her with the same sensory cues that are used by the driver in real world driving (Allen & Rosenthal, 1994). The sensory cues used by the driver to accomplish a driving task may include visual, motion, haptic, and auditory cues. Motion cues include vestibular cues, sensed by vestibular organs in the inner ear, and proprioceptive cues, which inform us about the relative position and motion of our body parts and originate from sensors (proprioceptors) in muscles, tendons, and joints (Schmidt & Lee, 1999). The importance of each of these cues depends on the driving task being performed. Although some experiments have shown that human drivers are able to perform certain maneuvers based solely on visual information, other experiments have demonstrated significant influence of the other types of sensory cues (e.g. Siegler et al., 2001). Motion cues, particularly, have been shown to be essential to many driving tasks while haptic and auditory cues often have less importance (Macadam, 2003). The goal of this study was to investigate the role of motion cues in driving an agricultural vehicle in parallel swathing mode.

Straight line driving of an agricultural vehicle with a lightbar guidance system falls in the category of compensatory manual control tasks. In compensatory manual control tasks the only input to the driver is the error, or the difference between system response and the reference (ideal) response (Fig. 1). The task is therefore to minimize the instantaneous error, e, without direct reference to the response, m, of the controlled element (Jagacinski and Flach, 2002).

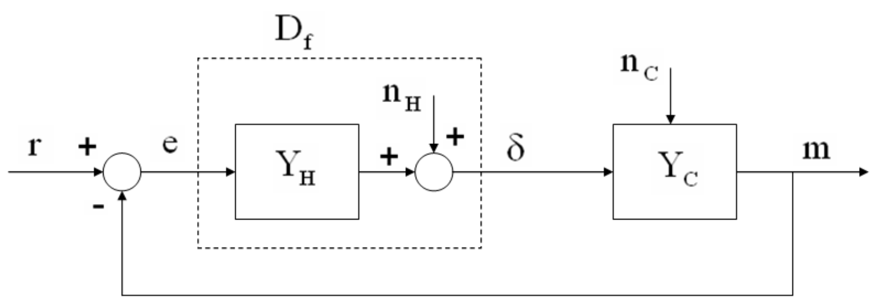

Fig. 1. Compensatory control task of human operator (Jagacinski & Flach 2002).

The control actions of the human operator consist of two parts. The first part, usually represented by a linear transfer function, Y_H, includes that portion of human output which is correlated with his/her input. The second part, n_H, is called remnant and includes the portion of human output that cannot be obtained from his/her input by a linear operation. Remnant, n_H, is usually quantified by its power spectral density. Y_C is the controlled element and n_C is any possible disturbance acting on it. The output, m, of the controlled element is subtracted from the reference input, r, and the difference, e, is presented to the operator by a display.

The theory of human compensatory control was developed and published by McRuer based on extensive experimental data (McRuer and Weir, 1969). He developed what is known as the crossover model of human operator:

$$Y_H . Y_C = \frac{\omega_c \, e^{-j\omega\tau_e}}{j\omega} \qquad (1)$$

The model suggests that the human operator adjusts his/her control dynamics, Y_H, so that the combined open-loop gain $|Y_H . Y_C|$ decreases with frequency with a slope of -20 db/decade. ω_c is the crossover frequency (frequency at which $|Y_H . Y_C| = 1$) and $\exp(-j\omega\tau_e)$ represents the delays in Y_H and Y_C.

McRuer's experiments also showed that the human operator's control can be satisfactorily described by a model of the following form:

$$Y_H(j\omega) = \left[\frac{\exp(-j\omega\tau_H)}{T_N j\omega + 1}\right]\left[\frac{K(T_L j\omega + 1)}{T_l j\omega + 1}\right] \qquad (2)$$

The first term on the right of Eq. 2 represents the inherent limitations of the human operator and includes the reaction delay, τ_H, and a first order lag, inherent in the neuromuscular system, with time constant T_N. The second term includes a gain, K, as well as a lead term and a lag term with time constants T_L and T_l, respectively, and represents the human operator's equalization. The human operator adjusts these three parameters to satisfy some performance criterion such as the minimization of root-mean-square (RMS) of error (e in Fig. 1).

MATERIALS AND METHODS

Experiments were conducted in the summer of 2007 in field plots on the campus of the University of Manitoba, Canada. Seven experienced tractor drivers drove a John Deere tractor (model 5425) with an Outback S® lightbar guidance system. An RTK GPS system (Leica GPS1200) was used to record the exact position of the tractor.

The simulator experiments were performed using the tractor-driving simulator located in the Agricultural Ergonomics Laboratory in the Department of Biosystems Engineering, University of Manitoba. The simulator provides visual feedback with a horizontal field-of-view of 65° and torque feedback on the steering wheel.

Field measurements had been previously performed on a single tractor and a single lightbar guidance system to estimate the disturbance on the tractor, n_C, and the error of the guidance system, r, and the results were implemented in the driving simulator (Karimi et al., 2008). Signal r has a bandwidth 0.045Hz-0.221Hz and RMS of 14 cm while signal n_C has a bandwidth 0.150Hz-0.890Hz and RMS of 6 cm. During the simulator experiments, the following data were recorded and saved with a frequency of 20 Hz by the main computer: position of tractor in the x and y directions and its heading, steering wheel angle and the values of signals n_C and r.

The tractor driving simulator used in this study provides only yaw motion. An electric motor and a screw mechanism are used to turn the whole cab around an axis that approximately passes through the driver's seat. According to Crolla (1983), most other motion cues when driving agricultural vehicles are negligible.

As mentioned before, all of the signals δ, e, m, r, and n_C in Fig. 1 were recorded in the simulator experiment. Therefore, we were able to use system identification techniques to estimate the value of the parameters of the human operator model presented in Eq. 2. System Identification procedures in Matlab were used for this purpose. System identification using a prediction error method (Ljung, 1987) was used. The input to the driver is the error, e, in meters and the output from the driver is the steer angle of the front wheel.

RESULTS AND DISCUSSION

The data were divided into one-minute pieces and analysis was performed on each piece separately. Tests of stationarity such as those suggested by Bendat and Piersol (1986) showed that one-minute-long pieces of the collected data were stationary. The identified parameters were usually significantly different for the first couple of minutes of each simulator experiment. Therefore, the first 5 min of data for each experiment were ignored. Table 1 shows the average values, for the last 10 min, of the identified parameters for each of the two experimental conditions as well as the analysis of variance results.

Table 1. Values of parameters of driver model obtained through system identification. Different superscripts in the same column show significantly different values.

Experimental condition	K	T_L	T_N	T_I	τ_H
With motion cues	0.12[a]	1.16[a]	0.07[a]	0.36[a]	0.43[a]
Without motion cues	0.16[b]	2.40[b]	0.09[a]	0.40[a]	0.40[a]

When motion cues were present, the subjects showed a significantly smaller gain and a smaller time lead constant. These are indicative of a more relaxed driving style (Chen and Ulsoy, 2006).

Open-loop frequency response of the human plus controlled element was also obtained. Figure 2 shows a typical bode plot for a single driver for the experiments with and without motion cues. An interesting observation is the low value of the crossover frequency. This value is 0.85 rad/s for the experiment without motion cues and 0.55 rad/s for the experiment with motion cues; both of these values are much smaller than the value predicted based on McRuer's experiments. This is because when the frequency of the disturbances on the system become close to the crossover frequency, the human operator suddenly acts to significantly decrease the crossover frequency by reducing his gain, K. This phenomenon is called the crossover regression (Hess, 1997). For a nonhuman controller, such a decrease in the crossover frequency would result in a significant increase in the tracking error, e. However, in the case of a human controller this phenomenon will result in lower tracking errors than if crossover regression does not happen. The reason for this has to do with the human remnant, n_H. It can be shown that the remnant power is proportional to the square of tracking error or its power (McRuer & Weir, 1969). Therefore, if crossover regression does not happen, an increase in remnant power, due to bandwidth of the disturbance, would result in a substantial increase in tracking error. In other words, human operator ignores the high frequencies by lowering his gain and, therefore, the open-loop crossover frequency. This is the strategy that human operators automatically adopt because responding to high frequency commands and disturbances would introduce so much remnant that will, in effect, have a negative impact on performance.

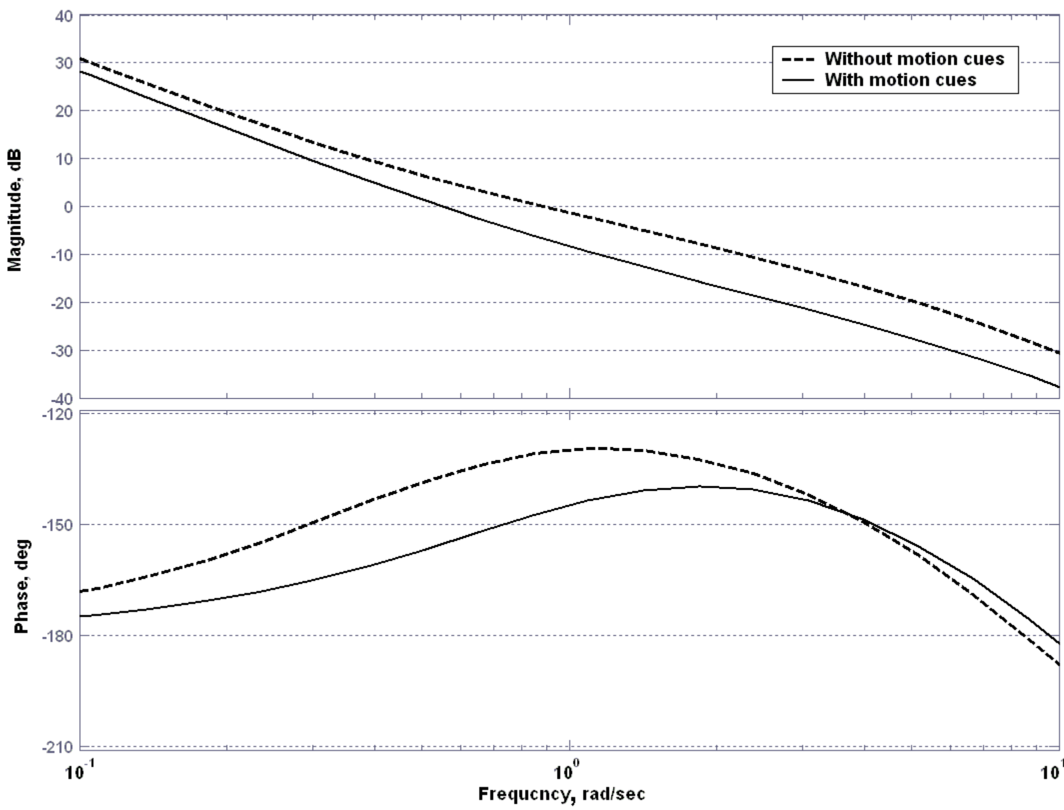

Fig. 2. Open-loop bode plot for the human plus tractor model combination.

Table 2 provides more support for this observation. This table shows the values of the root mean square (RMS) of driving error and steering wheel angle for the two simulator experiments and the field experiment. The values shown in this table are the averages for all subjects. As shown, when the motion feedback was disabled, the control effort of the subjects, as assessed by the RMS of steering wheel angle, increased, while their performance, as assessed by the RMS of lateral deviations, deteriorated. Both of these changes were significantly different on a 95% confidence level.

Table 2. Comparison of field experiment results with the results of the driving simulator experiments. Different superscripts within the same column indicate significantly different means.

	RMS of lateral deviations, cm	RMS of steering wheel angle, degree
Field experiment	30[a]	Not measured
Simulator experiment with motion cues	34[a]	13[a]
Simulator experiment without motion cues	39[b]	19[b]

CONCLUSIONS

The goal of this study was to investigate the role of motion cues in driving an agricultural vehicle on straight lines. The results show a significant decrease in control activity and an improvement in performance in the presence of motion cues. The results indicate the importance of motion feedback for a tractor driving simulator. The results also suggest that the best way to drive in parallel swathing mode with a lightbar guidance system is to use yaw motion of the tractor as an additional cue and to try to null errors with small steering wheel angle inputs. This would result in a more relaxed driving and improved performance. A bad strategy would be to respond to the error shown on the lightbar with large steering inputs.

REFERENCES

Allen, R.W. and T.J. Rosenthal. 1994. Meeting important cuing requirements with modest, real-time, interactive driving simulations, SAE Paper 940228.

Bendat, J.S. and A.G. Piersol. 1986. Random Data- Analysis snd Measurement Procedures, Second Edition. New York, NY: John Wiley & Sons, Inc.

Chen, L.K and A.G. Ulsoy. 2006. Experimental evaluation of a vehicle steering assist controller using a driving simulator, Vehicle System Dynamics, 44(3), 223-245.

Crolla, D.A. 1983. The steering behavior of off-road vehicles. In Proceedings of 8th IAVSD Symposium. Cambridge, MA. 15-19 August.

George, C.F.P. 2003. Clinical Review; Driving simulators in clinical practice. Sleep Medicine Reviews, 7(4), 311-320.

Godley, S.T. 1999. A driving simulator investigation of perceptual countermeasures to speeding. Thesis submitted for the degree Doctor of Philosophy. Department of Psychology, Monash University, Australia.

Hess, R.A. 1997. Feedback control models- manual control and tracking. In Handbook of Human Factors and Ergonomics, ed. G. Salvendy, 1249-1294. New York City, NY: John Wiley & Sons, Inc.

Jagacinski, R.J. and J.M. Flach. 2002. Control Theory for Humans: Quantitative Approaches to Modeling Performance, First Edition. CRC Press.

Karimi, D., D.D. Mann and M.R. Ehsani. 2008. Modeling of straight-line driving for a tractor-driving simulator. (acceoted for publication by:) Applied Engineering in Agriculture.

Ljung, L. 1987. System Identification: Theory for the User. Englewood Cliffs, NJ: Prentice-Hall.

Macadam, C.C. 2003. Understanding and modeling the human driver. Vehicle System Dynamics, 40, 101–134.

McRuer, D. and D.H. Weir. 1969. Theory of manual vehicular control. IEEE Transactions on Man Machine Systems, 10(4), 257 – 291.

Rakauskas, M.E., L.J. Gugerty and N.J. Ward. 2004. Effects of naturalistic cell phone conversations on driving performance. Journal of Safety Research, 35, 453– 464.

Schmidt, R.A. and T.D. Lee. 1999. Motor Control and Learning; A Behavioral Emphasis, Third edition. Champaign, IL: Human Kinetics.

Siegler, G., G. Reymond, A. Kemeny and A. Berthoz. 2001. Sensorimotor integration in a driving simulator: contributions of motion cueing in elementary driving tasks. Driving Simulator Conference DSC, 21-32. Sophia Antipolis, France. September 2001.