MÖBUS, C., HÜBNER, S., GARBE, H., *Driver Modelling: Two-Point- or Inverted Gaze-Beam-Steering,* in M. Rötting, G. Wozny, A. Klostermann und J. Huss (Hrsgb), Prospektive Gestaltung von Mensch-Technik-Interaktion, 7. Berliner Werkstatt Mensch-Maschine-Systeme, 10. - 12. Oktober 2007, Berlin, Fortschritt-Berichte VDI-Reihe 22, Nr. 25, 483 – 488, Düsseldorf: VDI Verlag, 2007, ISBN 978-3-18-302522-0

Driver Modelling: Two-Point- or Inverted Gaze-Beam-Steering

Claus Möbus, Swen Hübner & Hilke Garbe[1]

Abstract

Modelling drivers' behaviour is essential for developing error compensating assistance systems (Cacciabue, 2007). Salvucci (2007) recommends one of those, the *Two-Point Visual Control Model of Steering (TPVCMOS;* Salvucci & Gray, 2004), as the backbone of an integrated cognitive architecture. We discuss the shortcomings of this model from two standpoints: the empirical basis of human steering behaviour and a simulation study of a reconstructed *TPVCMOS* in the TORCS racing simulation environment. As a result, we recommend a steering model that differs from the *TPVCMOS* in several aspects: *peripheral* visual control instead of a near point, an integrated information sampling mechanism for *both* lateral and longitudinal control (*inverted-beam steering*), and *active gaze control* to model driving manoeuvres which depend on *cognitive* planning. Unfortunately, there is a dearth of empirical studies with sufficiently large sample sizes relating active gaze control and driving behaviour. We expect there a change in the future.

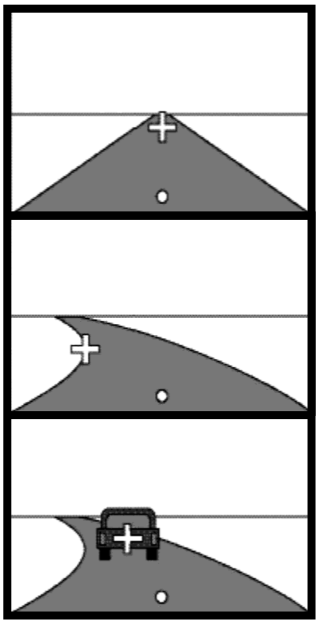
Salvucci & Gray Model (2004)

Control-theoretical driver models (Jürgensohn, 2007; Weir & Chao, 2007) are well known. Recently, computational *integrated* cognitive models based on schemas or frames (Bellet et al., 2007) and production systems (Salvucci, 2007) have been proposed. The integrated Salvucci model (2007) contains the *TPVCMOS* as a basic component but only for lateral control. Despite that, the *TPVCMOS* seems to have attractive attributes like conceptual simplicity and empirical grounding: *As a control model of steering behaviour, the model nicely fits various aspects of human steering behaviour found in recent empirical studies* (Salvucci, 2007, p.358). *TPVCMOS* implements the hypothesis that steering activities are controlled by two visual signals acquired from the road – the far and the near point (Fig. 1, left): *The critical distinction between our model and most previous models is that our model explicitly utilizes near and far information, and uses only perceived visual direction to these points to guide steering* (Salvucci, 2007, p.357). The situation determines the selection of the far point: *escape point, tangent point, and front vehicle* (Fig. 1, left). The same hypothesis is reported by Land (1998; Fig. 2). The *TPVCMOS* controller works according

[1] Department of Computing Science, University of Oldenburg, D-26111 Oldenburg, Germany, email: claus.moebus@uni-oldenburg.de

MÖBUS, C., HÜBNER, S., GARBE, H., *Driver Modelling: Two-Point- or Inverted Gaze-Beam-Steering,* in M. Rötting, G. Wozny, A. Klostermann und J. Huss (Hrsgb), Prospektive Gestaltung von Mensch-Technik-Interaktion, 7. Berliner Werkstatt Mensch-Maschine-Systeme, 10. - 12. Oktober 2007, Berlin, Fortschritt-Berichte VDI-Reihe 22, Nr. 25, 483 – 488, Düsseldorf: VDI Verlag, 2007, ISBN 978-3-18-302522-0

to three criteria (Salvucci & Gray, 2004, p. 1237): a stable far point, $\dot{\theta}_f \approx 0$; a stable near point, $\dot{\theta}_n \approx 0$; and a near point centred on the roadway $\theta_n \approx 0$ (Fig. 1).



Salvucci's PI-Controller (continous time)

$$\varphi = k_f\theta_f + k_n\theta_n + k_I\int\theta_n dt$$

with $\theta_f, \theta_n = error$ (angles between heading and near and far points)
and φ = steering angle
and k_f, k_n, k_I unknown parameters

$$\dot{\varphi} = k_f\dot{\theta}_f + k_n\dot{\theta}_n + k_I\theta_n$$

Salvucci's PI-Controller (discrete time)

$$\Delta\varphi = k_f\Delta\theta_f + k_n\Delta\theta_n + k_I\theta_n\Delta t$$

Fig. 1: Salvucci & Gray *TPVCMOS*-Model (2004)

Due to its attractive properties, the *TPVCMOS* seems to be a good candidate for being the backbone of a more skilled driver model. These range from (1) its conceptualization of a simple controller with only two reference input variables (far and near point), (2) its *composition of a „lower-level“ control model into a production system model of highway driving* (Salvucci, 2007, p.357), (3) modelling the eye-steering coordination with a PI-controller, (4) its reuse of Anderson's (2004) well known cognitive architecture ACT-R, to (5) its seemingly solid empirical foundation by the work of Land et al. (1994, 1995, 1998) and their validation experiments related to *curve negotiation*, *corrective steering* and *lane changing* (Salvucci & Gray, 2004).

Empirical Evidence and the Two-Point-Steering-Model

Mainly, the experiment of Land & Horwood (1995), leaving only small *visual segments* for viewing the road, provided the empirical foundation for the *TPVCMOS model*. Land & Horwood formulated the hypothesis that the quality of driving increases with the horizontal angle of separation of two visual segments (Land et al., 1994, 1995, 1998). These segments were fixed for each trial although driving took place on curved roads. All these assumptions are implemented in the *TPVCMOS*. Unfortunately, the model incorporates only the competence of lateral control at the constant speed of as little as 60.84 km/h. Such a slow speed makes longitudinal control unnecessary, resulting in a model with severely questionable validity.

MÖBUS, C., HÜBNER, S., GARBE, H., *Driver Modelling: Two-Point- or Inverted Gaze-Beam-Steering,* in M. Rötting, G. Wozny, A. Klostermann und J. Huss (Hrsgb), Prospektive Gestaltung von Mensch-Technik-Interaktion, 7. Berliner Werkstatt Mensch-Maschine-Systeme, 10. - 12. Oktober 2007, Berlin, Fortschritt-Berichte VDI-Reihe 22, Nr. 25, 483 – 488, Düsseldorf: VDI Verlag, 2007, ISBN 978-3-18-302522-0

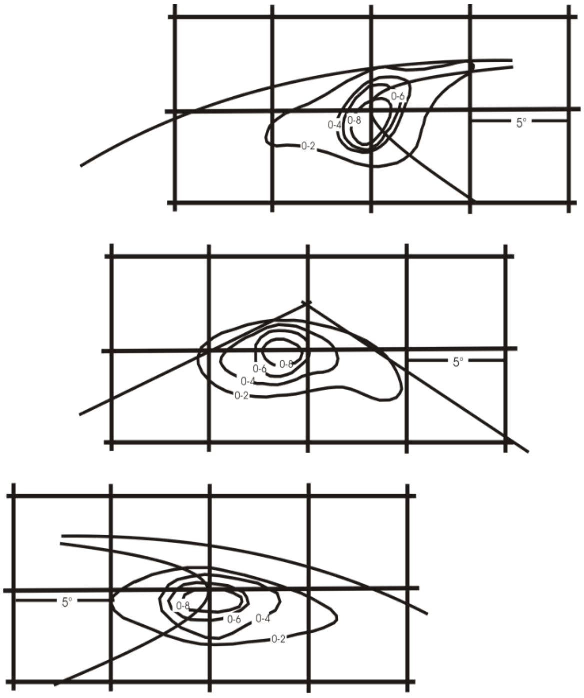


Fig. 2: Eye-Fixation Contours (Land, 1998) with N=3

A reanalysis of the experiment of Land & Horwood (1995) raises doubts concerning the hypothesis of *two separated* horizontally fixed information points. Land agrees with us that a replication of the experiment with modified experimental conditions could recuperate the hypothesis of a *single* attention controlled visual field. This field is supposed to be controlled laterally *and* horizontally: *You could be right … With regard to a moving segment … this is sampling various parts of the road in time, so is almost equivalent to sampling in space by having more than one segment* (Land, 2007).

Wilkie & Wann (2003) believe that the *near* point (Salvucci & Gray: 6.2 m distance) could be substituted by peripheral perception. In addition, they demonstrate that drivers sample less information from the tangent point but more from the midpoint of the road: *sampling was predominantly of areas proximal to the centre of the road* (Wilkie & Wann, 2003, p.677; Fig. 3). Unfortunately, the simulation study of Wilkie and Wann suffers from methodological weaknesses, too. The simulated road has a width of only 2 (!) m and the car's speed was only 29 (!) km/h.

Simulation of Two-Point-Steering-Model in the TORCS-Simulator

More doubts on the *TPVCMOS* came up in a simulation study of our own (Hübner, 2007) using a reimplementation of *TPVCMOS* in the TORCS-Simulator (TORCS, 2007). We did not reuse the Lisp-Code but implemented the model as a virtual TORCS-driver based on details of the Salvucci & Gray (2004) publication. All simulation drives ran at much higher speeds than in the experiment of Salvucci & Gray. The speed was chosen so that no braking before curves was necessary. All runs with best lap times at speeds up to 149.4 km/h and varying road widths showed that the PI-controller *TPVCMOS* could be *simplified* to a P-controller ($k_f <> 0$, $k_n = k_i = 0$) or a One-Point-Steering Model.

Furthermore, we realized that the *exclusive* use of a tangent point (especially in S-curves) was not possible for geometric reasons. Similar to Wilkie & Wann (2003) and the real implementation of Salvucci & Gray (2004; comment in lisp-code line 297, file simulation.lisp: *tangent point or far middle point, whichever is closer*) far and near point were located at the centre of the roadway

MÖBUS, C., HÜBNER, S., GARBE, H., *Driver Modelling: Two-Point- or Inverted Gaze-Beam-Steering*, in M. Rötting, G. Wozny, A. Klostermann und J. Huss (Hrsgb), Prospektive Gestaltung von Mensch-Technik-Interaktion, 7. Berliner Werkstatt Mensch-Maschine-Systeme, 10. - 12. Oktober 2007, Berlin, Fortschritt-Berichte VDI-Reihe 22, Nr. 25, 483 – 488, Düsseldorf: VDI Verlag, 2007, ISBN 978-3-18-302522-0

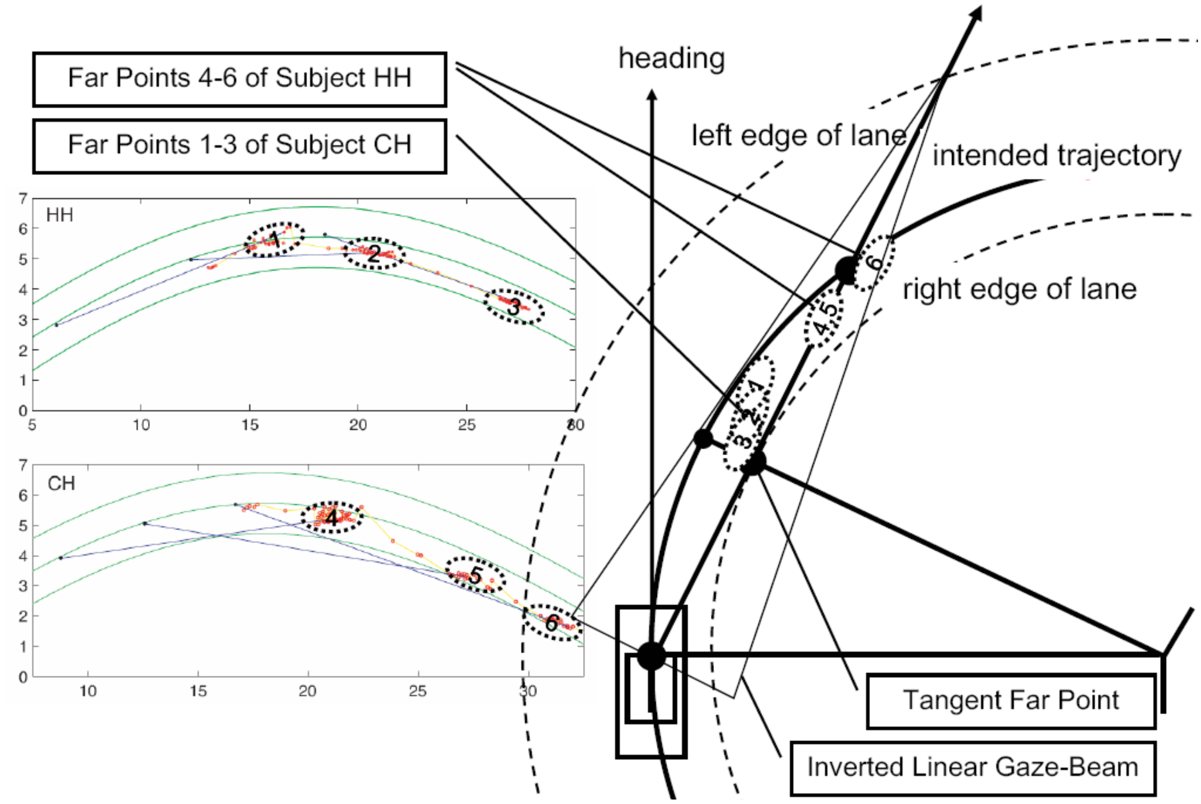


Fig. 3: Wilkie's & Wann's (2003) far points (left), their projections, and Inverted Linear Gaze-Beam Hypothesis (right)

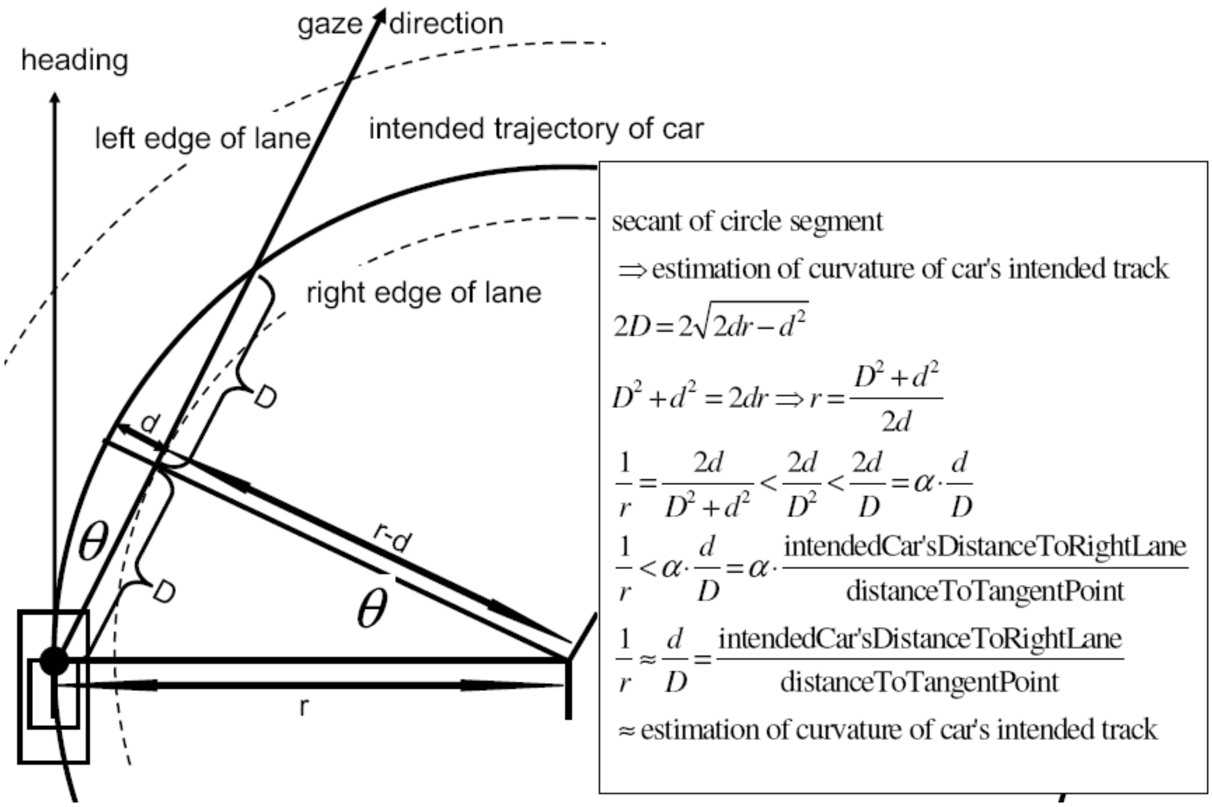


Fig. 4: Heuristic Estimation of the Curvature of an Unknown Curve

MÖBUS, C., HÜBNER, S., GARBE, H., *Driver Modelling: Two-Point- or Inverted Gaze-Beam-Steering,* in M. Rötting, G. Wozny, A. Klostermann und J. Huss (Hrsgb), Prospektive Gestaltung von Mensch-Technik-Interaktion, 7. Berliner Werkstatt Mensch-Maschine-Systeme, 10. - 12. Oktober 2007, Berlin, Fortschritt-Berichte VDI-Reihe 22, Nr. 25, 483 – 488, Düsseldorf: VDI Verlag, 2007, ISBN 978-3-18-302522-0

in an angle to the horizon similar Salvucci & Gray (2004) chose for their far point. We fixed the horizontal position of the far point for all curves of a round trip similar the implementation in *TPVCMOS*.

Integration of Longitudinal Control

Improving the driving competence by the integration of longitudinal control (braking and accelerating) makes it necessary to sample more information from the visual field successfully enabling a curve dependent speed control. The angle information *TPVCMOS* uses is insufficient. There are several heuristics dealing with the estimation of curvature. Two rather cognitively implausible ones could be found in Land (1998, formula 8.1 and 8.2). Other heuristics suggest the possibility of estimating the curvature of *unknown* curves. Our proposal (Fig. 4) combines three features: cognitive simplicity, plausibility, and suitability for driving unknown curves. A common drawback of *all* heuristics is that they contain *ad hoc* assumptions concerning the scan of the visual field and the cognitive operations of the driver, which are hard to identify empirically. As an example, it is nearly impossible to decide whether a driver is estimating the angle theta or the distance d (Fig. 4).

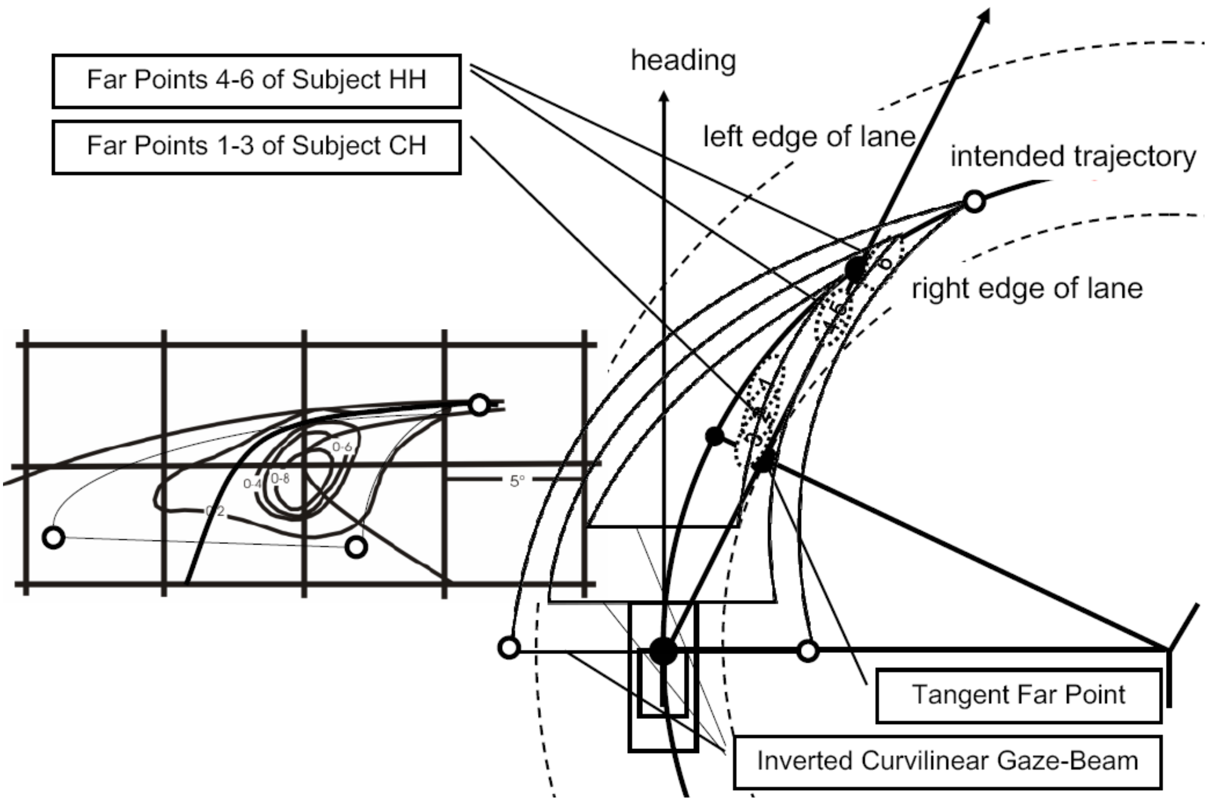


Fig. 5: Sampling Contours of Inverted Curvilinear Gaze-Beam Hypothesis (left: driver's view, right: bird's eye view)

Inverted Gaze-Beam Hypothesis, Cognition, and Learning Abilities

One drawback for the model construction is the imperfect reliability of viewing data and the imperfect resolution of suitable measurement devices. This, together with the inability to identify the cognitive steps of the mental procedures by empirical data, suggests the proposal of driver models in a *more abstract* and *probabilistic* manner than Salvucci & Gray (2004) did. Thus, we abandon the hypothesis of a two-point-deterministic control model in favour of an inverted gaze-beam-steering model (Fig. 3, 5) with probabilistic eye-fixation contours.

As both figures show, the hypothesis of an inverted gaze-beam-steering is compatible with both findings of Land (1998) and Wilkie & Wann (2003).

More doubts concerning pure *perception-orientated control* models like the *TPVCMOS* arise by their inability to interpret the roadway as humans do. They are able to cut curves but are unable to drive planned manoeuvres like "Ausholmanöver" (enlarging the radius of the curve by driving away from the tangent point). A *cognitive* driver model is able to drive such a manoeuvre by increasing the distance D and trying to fix the distance d to a constant value (Fig. 4), thus flattening the curve and trying to drive at a faster speed.

Another drawback of *TPVCMOS* is the inability to model the learning behaviour of novice drivers: *the improvement seemed to be related to a small, but significant, increase in look-ahead distance* (Wilkie et al., 2004).

References

Bellet, Th., Bailly, B., Mayenobe, P. & Georgeon, O., 2007, Cognitive Modelling and Computational Simulation of Drivers Mental Activities, in: Cacciabue, P.C., 2007, p. 315 – 343

Cacciabue, P.C., 2007, Modelling Driver Behaviour in Automotive Environments, London: Springer, ISBN-10: 1-84628-617-4

Chattington, M., Wilson, M., Ashford, D. & Marple-Horvat, D.E., 2007, Eye-Steering Coordination in Natural Driving, Experimental Brain Research, 180, 1-14

Hübner, S., 2007, Rekonstruktion des Two-Point Steering Driver Models von Salvucci, BA-Thesis, Department of Computing Science, University of Oldenburg

Jürgensohn, Th.,2007, Control Theory Models of the Driver, in: Cacciabue, 2007, p.277 – 292

Land, M., 2007, personal communication (email)

Land, M.F., 1998, The Visual Control of Steering, in L.R. Harris & M. Jenkin (eds.), Vision and Action, Cambridge: Cambridge University Press, 163-180

Land, M. & Horwood, J.,1995, Which Parts of the Road Guide Steering?, Nature,377,339–340

Land, M. & Lee, D.N., 1994, Where we look when we steer, Nature, 369, 742-744

John Manslow, 2004, Using Reinforcement Learning to Solve AI Control Problems, in S. Rabin (ed), AI Game Programming Wisdom 2, p. 591 - 601

Salvucci, D.D., & Gray, R., 2004, A Two-Point Visual Control Model of Steering, Perception, 33, 1233 – 1248

Salvucci, D.D., 2007, Integrated Models of Driver Behavior, in: Gray, W. D. (Ed.), 2007, *Integrated models of cognitive systems*. New York: Oxford University Press, p. 356 - 367

TORCS, 2007, http://torcs.sourceforge.net/

Weir, D.H. & Chao, K.C., 2007, Review of Control Theory Models for Directional and Speed Control, in: Cacciabue, P.C., 2007, , p. 293 – 311

Wilkie, R. M., Poulter, D. R., & Wann, J. P. (2004). Where You Look When You Learn to Steer, Journal of Vision, 4(8), 1a, http://journalofvision.org/4/8/1/, doi:10.1167/4.8.1.

Wilkie, R.M. & Wann, J.P., Eye-Movements Aid the Control of Locomotion, Journal of Vision, 2003, 3, 677-684