EPSRC PROJECT EP/D004152/1

Active Multi-Axle Steering of Heavy Goods Vehicles

PROJECT DETAILS

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Project Duration: 41 Months

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PROJECT SUMMARY

Research world-wide has shown that long combination vehicles (LCVs), with two or more trailers can significantly reduce road congestion, improve safety, improve transportation cost efficiency, reduce fuel use and greenhouse gas emissions and significantly reduce road surface wear. Three major technical barriers prevent adoption of LCVs in the UK: (i) poor manoeuvrability; (ii) poor high speed stability; and (iii) poor reversibility. This project aimed to address these issues through investigation of technologies to steer automatically, the trailer wheels of articulated heavy goods vehicles.

The original objectives of the project are listed below along with a summary of key project outcomes. All references shown in brackets [ ] and links to photographs and videos can found at: www.cvdc.org/epsrc_summary

*** Investigate active steering control strategies for tractor-semitrailer combinations:** Control strategies were devised for active steering of tractor-semitrailer vehicles at low speed [2, 5] and high speed [4, 8]. The controllers were field tested on an existing experimental vehicle. Low speed performance benefits on the standard UK roundabout manoeuvre included a 72% reduction in steady-state off-tracking and an 83% reduction in peak tyre force while eliminating entry tail-swing. This contrasted with a 260% increase in tail swing for a conventional trailer steering strategy [15]. At high speed, a 27% reduction in lateral acceleration during a lane-change manoeuvre was achieved with no increase in off-tracking [4].

*** Devise and test prototype active steering hardware and software for fail-safe, efficient operation**. A new fail-safe steering actuation system was designed, built and fitted to a new test trailer [10]. A comprehensive investigation of all possible

failure modes was performed [1]. The ultimate design incorporated novel fail-safe, self configuring control software [9].

*** Develop and test active steering strategies for a selection of long combination vehicles.** Control strategies were developed to be applicable to a range of common LCVs at low and high speeds. These strategies were field tested using the actively steered 7-axle B-double vehicle developed during this project. At low speed 'perfect' following of the tractor path was achieved with both trailers, using less swept path width than a conventional tractor-semitrailer, and causing no tail-swing. By contrast an unsteered B-double was not able to negotiate the roundabout, and a conventional steering strategy showed a hazardous 1.6m of tail-swing [10]. Simulations show a 17% decrease in rearward amplification and an 80% reduction in transient off-tracking at high speed [11].

* I**nvestigate control strategies for active steering of conventional and long combination vehicles in the reverse direction**. A path-following control strategy was developed to enable the same manoeuvres to be performed in reverse as in the forward direction. During field tests with this controller, the actively steered B-double was able to negotiate the UK roundabout manoeuvre in reverse with nearly perfect path following: an impossible task for an unsteered vehicle [12].

*** Quantify the costs and benefits of actively steered conventional and long combination vehicles.** Two cost-benefit analyses were performed [17, 18]. Potential benefits of introducing LCVs in the UK include: £2.1b p.a. reduction in costs associated with traffic congestion and up to 40% reduction in CO2 from freight transport. A detailed follow-on study further quantified the potential for reducing CO2 [6, 7, 19. 20].

Beneficiaries of the technologies developed in this project include: the environment (reduced CO2 emissions); the public (safer, less road-damaging vehicles); vehicle operators (more efficient and versatile vehicles), Department for Transport (new knowledge about performance and benefits of LCVs); industrial partners (exploitation of the technology).

PUBLICATIONS

Journals

1. Odhams, AMC; Roebuck, RL; Cebon, D and Winkler, CB 'Dynamic safety of active trailer steering systems'. *Proc. IMechE, Part K: J. Multi-body Dynamics*, 2008, **222**(K4), pp367-380.
2. Jujnovich, BA and Cebon, D. 'Path-following steering control for articulated vehicles'. Sub to ASME Journal of Dynamic Systems Measurement and Control, August 2008.

3. Cheng, C. and Cebon, D. 'Parameter and State Estimation for Articulated Heavy Vehicles' Accepted for publication in VSD Special Issue on Advanced Suspensions, March 2009.
4. Cheng, C, Roebuck, R, Odhams, AMC, and Cebon, D. 'High-speed optimal steering of a tractor-semitrailer' VSD, June 2009 (in print).
5. Cheng, C, Odhams, AMC, Roebuck, RL, and Cebon, D, 'Feedback control of semitrailer steering at low speeds. Sub to IMechE J Auto Eng, August, 2009.
6. Odhams, AMC, Roebuck, RL, Lee, YJ, Hunt, S, Cebon, D 'Factors Influencing the Energy Consumption of Road Freight Transportation', sub to Proc IMechE Part C, J Mech. Eng, Sci.
7. Hunt, S, Odhams, AMC, Roebuck, RL, Cebon D. 'Parameter measurement for heavy vehicle energy consumption modelling', IMechE J Auto
8. Odhams, AMC, Roebuck, RL, Jujnovich, BA, Cebon, D 'Active steering of a tractor-semitrailer', sub to Proc IMechE, J Auto. Eng.
9. Roebuck, RL, Odhams, AMC, Cebon, D. 'An automatically-reconfigurable software-based safety system for rear-steering multi-unit vehicles', sub to IEEE Transactions on Automatic Control

Journal Articles in preparation:

10. Implementation of trailer steering control on a multi-unit vehicle at low speeds, Roebuck, Odhams, Cebon, ASME J Dyn Sys Meas Control (in preparation)
11. High-speed optimal steering of multiply-articulated heavy vehicles, Cheng, Roebuck, Odhams, Cebon, IMechE, J Auto(in preparation)
12. Reversing of a double-articulated heavy vehicle, Odhams, Roebuck, Cebon, (in preparation)
13. Implementation of trailer steering control of a multi-unit vehicle at high speeds, Roebuck, Odhams, Cheng, Cebon, (in preparation)

Conferences Papers

14. Cheng, C. and Cebon, D. 'Improving roll stability of articulated heavy vehicles using active semi-trailer steering', 20th IAVSD Symposium 13-17 August, 2007 Berkeley, California. Published in Vehicle System Dynamics, Volume 46, Issue S1 & 2 2008 , pages 373 – 388. DOI: 10.1080/00423110801958576
15. Jujnovich, BA, Roebuck, RL, Odhams, AMC and Cebon, D. 'Implementation of active rear steering of a tractor-semi-trailer'. Proc 10th International Symposium on Heavy Vehicle Transport Technology, Paris, 2008.
16. Jujnovich, BA, , Odhams, AMC, Roebuck, RL and Cebon, D. 'Active Rear Steering Control of a Tractor - Semi-Trailer', Proc 9th International Symposium on Advanced Vehicle Control, AVEC'08, 2008. Kobe, Japan.

Reports

17. Hall, B, Odhams, A and Cebon, D. 'Social appraisal: active multi-axle steering of heavy goods vehicles', Technical Report CUED/C-MECH/TR.91, 2007.

18. Davies, K. 'Assessing the business case for production of multi-axle steering systems for heavy goods vehicles at Arvin Meritor, Wrexham', 28 August, 2008.

19. Odhams, AMC, Roebuck, RL, Lee, YJ and Cebon, D. 'Energy Use in Heavy Vehicles', Technical Report CUED/C-MECH/TR.94, ISSN 0309-7420, August 2008.

20. Hunt, S, Odhams, AMC, Roebuck, RL, and Cebon, D. 'Modelling the fuel consumption of heavy vehicles', Technical Report CUED/C-MECH/TR.95, ISSN 0309-7420, August 2009.

Patents

21. 'Steerable wheel safety system', 2006, British Patent Application No 0619529.1, with B Jujnovich and A Dixon, 3 October. PCT/GB2007/003731.

22. 'Active steering controller', 2007, British Patent Application No 0715142.6, with B Jujnovich and C Cheng, 0715142.6. PCT/GB2008/002614.

Theses

23. Cheng, C. 'Enhancing safety of actively-steered articulated vehicles', , University of Cambridge, PhD Dissertation, March 2009.