e-vectoorc
Electric-Vehicle Control of Individual Wheel Torque for On- and Off-Road Conditions
01 September 2011 - 31 August 2014

The research receives funding from the European Community Seventh Framework Programme (FP7/2007-2013) under grant agreement No 284078

**E-VECTOORC**
**Electric Vehicle Control of Individual Wheel Torque for On- and Off-Road Conditions**
**FP7-INFSO-284078**

# Deliverable D8.4
# Final Dissemination Report

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## E-VECTOORC Consortium

| Participant organisation name | Part. short name | Country |
|---|---|---|
| University of Surrey (Coordinating Institution) | SURREY | UK |
| Technische Universität Ilmenau | TUIL | Germany |
| Jaguar and Land Rover | JLR | UK |
| Flanders DRIVE | FLANDERS | Belgium |
| Inverto | INV | Belgium |
| Fundacion CIDAUT | CIDAUT | Spain |
| Instituto Tecnológico de Aragón | ITA | Spain |
| VIF Kompetenzzentrum - Das virtuelle Fahrzeug, Forschungsgesellschaft mbH | VIF | Austria |
| ŠKODA AUTO a.s. | SKODA | Czech Republic |
| TRW Automotive Lucas Varity GmbH | TRW | Germany |

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## Revision History

| Revision | Date | Description | Issued by |
|---|---|---|---|
| 1.0 | 01st August 2014 | Preliminary version | Valentin Ivanov (TUIL) |
| 2.1 | 26th Sep 2014 | Intermediate version | Phil Barber (JLR) |
| 3.0 | 29th September 2014 | Final Version | Valentin Ivanov (TUIL) |

## Abstract

The following document describes the dissemination activities of the E-VECTOORC project during year 3. The report includes:

- Public dissemination and promotion activities promotion activities;
- Research and technology presentation activities;
- Other information relevant to the dissemination of the project results.

**Keywords:** Dissemination, promotion activities, presentation activities, stakeholders

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# 1 Coordination of dissemination activities in the E-VECTOORC consortium

During the third year of the E-VECTOORC project the dissemination activities have been continuously carried out in accordance with the targets indicated in the project description and specified after the completion of the second year of the project in Deliverable 8.3. All consortium partners have taken an active part in the tasks of the "Dissemination and Exploitation" work package (WP8). The leader of WP8 is the project partner TUIL (Ilmenau University of Technology).

During the reporting time, the ongoing and expected dissemination activities were discussed and reviewed at the following meetings:

- The year 2 review meeting, Lommel (Belgium), 11.10.2013 – revision of the dissemination results obtained in the second year of the project and approval of the dissemination plan for the third year of the project. In particular, the publication and outreach activities plan has been updated in accordance with recent project results; The exploitation plan for the third year of the project and post-project prospects has been introduced and approved.
- The 27-month review meeting, conference call, 11.12.2013 – refinement of the publication plan and review of the first patent application procedure (Ilmenau University of Technology, Aragon Technological Institute and Flanders' Drive);
- The 30-month review meeting, Zaragoza (Spain), 26.03.2014 – preparation of the E-VECTOORC Special Session at 2014 FISITA World Automotive Congress (see section 4);
- The 33-month review meeting, Maastricht (The Netherlands), 04.06.2014 – refinement of the publication plan taking into account recent ABS tests on the E-VECTOORC vehicle demonstrator at the proving ground in Lommel (Belgium); preparatory activities for the final dissemination workshop at Gaydon, UK (see Section 4); introduction of plan for further patent applications.

The results of the dissemination activities are regularly published on the official E-VECTOORC web-site, http://www.e.vectoorc.eu. In particular, the project news was kept up-to-date and all conference presentations and other published materials were made

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accessible through the special dissemination page of the web-site. http://www.e-vectoorc.eu/en/view/links.html.

The next sections introduce the main components of the dissemination activities relevant to the third year of the project.

# 2 Research and technology presentation activities in year 3

## 2.1 Conference papers and presentations

The research results were presented at conferences, symposia and workshops to engage with the relevant scientific communities. The conference papers and presentations delivered in year 3 are listed in Table 1.

**Table 1** – Conference papers and presentations in year 3

| No. | Authors, Title | Event | Partners |
|---|---|---|---|
| 1 | Pennycott, A., De Novellis, L., Gruber, P., Sorniotti, A., Goggia, T. **'Enhancing the Energy Efficiency of Fully Electric Vehicles via the Minimization of Motor Power Losses'** | IEEE International conference on systems, man and cybernetics (SMC 2013), 13-16.10.2013, Manchester, England | SURREY |
| 2 | de Prada, L., González, M.I., Martín, J.S., Araujo, B., Cañibano, E. **'Regenerative-Friction Braking Distribution. Tool for the Comparison of Strategies and Vehicles Configurations'** | International Electric Vehicle Symposium & Exhibition, EVS 27, 17-20.11.2013, Barcelona, Spain | CIDAUT |
| 3 | Rodríguez, J.M., Meneses, R., Orús, J. **'Active Vibration Control for Electric Vehicle Compliant Drivetrains'** | IECON 2013 (Conference of the IEEE Industrial Electronics Society), 10-13.11.2013, Vienna, Austria | ITA |
| 4 | Gonzalez, M.I., Araujo, B., Martin, J.S., Cañibano, E. **'Optimized Regenerative Friction Braking Distribution in an Electric Vehicle with Four In-Wheel Motors'** | Advanced Microsystems for Automotive Applications (AMAA), 2013, 23-24.06.2014, Berlin, Germany | CIDAUT |
| 5 | Goggia, T., Sorniotti, A., De Novellis, L., Ferrara, A. **'Torque-Vectoring Control in Fully Electric Vehicles via Integral Sliding Modes'** | American Control Conference (ACC 2014), 04-06.06.2014, Portland, Oregon, USA | TUIL |
| 6 | Orús, J., Meneses, R., Rodríguez, J.M. **'Active Vibration Control for Torsional Oscillations in Powertrains for Fully Electric Vehicles'** | FISITA 2014 World Automotive Congress, 02-06.06.2014, Maastricht, the Netherlands | ITA, SURREY |

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| No. | Authors, Title | Event | Partners |
|---|---|---|---|
| 7 | Theunissen, J., Verhaege, K., van Aalst, S., Cruyt, O., De Smet, J., Battain, S., Verdaasdonk, R., Steenbeke, D., de Clercq, J. **'Powertrain Architecture of Electric Vehicles with Individually Controlled Switched Reluctance Motors'** | FISITA 2014 World Automotive Congress, 02-06.06.2014, Maastricht, the Netherlands | FLANDERS, INVERTO |
| 8 | Ivanov, V., Orús, J., Pütz, T., Brungs, F., Savitski, D., Shyrokau, B. **'Electric and Friction Braking Control Systems for AWD Electric Vehicles'** | FISITA 2014 World Automotive Congress, 02-06.06.2014, Maastricht, the Netherlands | TUIL, TRW |
| 9 | Pennycott, A., De Novellis, L., Sorniotti, A., Gruber, P. **'The Application of Control and Wheel Torque Allocation Techniques to Driving Modes for Fully Electric Vehicles'** | SAE 2014 World Automotive Congress, 08-10.04.2014, Detroit, USA | SURREY |
| 10 | Echeverría, I., Iglesias, M., Arteche, F., Piedrafita, J., Pradas, A., De Clercq, J. **'EMC mapping of a power train for fully electric 4 - wheel drive vehicle'** | EMC Europe Conference, 01-04.09.2014, Gothenburg, Sweden | ITA, INVERTO |
| 11 | Ivanov, V., Savitski, D., Augsburg, K., Knauder, B., Zehetner, J., Barber, P. **'Wheel Slip Control for All-Wheel Drive Electric Vehicle'** | The 18th International Conference of the ISTVS (International Society for Terrain Vehicle Systems), 22-25.09.2014, Seoul, Korea | TUIL, JLR, VIF |

## 2.2 Peer reviewed journal publications

Exceeding the targets set out in the project proposal, 10 papers have been published in year 3 (see Table 2). In addition, three journal papers are under review and more journal papers are currently in preparation.

**Table 2** – Journal publications in year 3

| No. | Authors, Title | Journal | Partners |
|---|---|---|---|
| 1 | De Novellis, L., Sorniotti, A., Gruber, P. **'Wheel Torque Distribution Criteria for Electric Vehicles With Torque-Vectoring Differentials'** | IEEE Transactions on Vehicular Technology, vol. 63(4), pp. 1593-1602, 2013 | SURREY |
| 2 | Pennycott, A., De Novellis, L., Sabbatini, A., Gruber, P., Sorniotti A. **'Reducing the Motor Power Losses of a Four-Wheel Drive Fully Electric Vehicle via Wheel Torque Allocation'** | Proceedings of the Institution of Mechanical Engineers: Part D-Journal of Automobile Engineering, vol. 228(7), pp. 830-839, 2014 | SURREY |

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| No. | Authors, Title | Journal | Partners |
|---|---|---|---|
| 3 | De Novellis, L., Sorniotti, A., Gruber, P., Pennycott, A. **'Comparison of Feedback Control Techniques for Torque-Vectoring Control of Fully Electric Vehicles'** | IEEE Transactions on Vehicular Technology, vol. PP (99), 2014 [in press] | SURREY |
| 4 | Pennycott, A., De Novellis, L., Gruber, P., Sorniotti, A. **'Optimal Braking Force Allocation for a Four Wheel Drive Fully Electric Vehicle'** | Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering, vol. 228(8), pp. 621-628, 2014 | SURREY |
| 5 | Pennycott, A., De Novellis, L., Sorniotti, A., Gruber, P. **'The Application of Control and Wheel Torque Allocation Techniques to Driving Modes for Fully Electric Vehicles'** | SAE International Journal of Passenger Cars – Mechanical Systems, vol. 7(2), pp. 488-496, 2014 | SURREY |
| 6 | Ivanov, V., Shyrokau, B., Savitski, D., Orús J., Meneses R., Rodríguez J.M., Theunissen J., Janssen K. **'Design and Testing of ABS for Electric Vehicles with Individually Controlled On-board Motor Drives'** | SAE International Journal of Passenger Cars – Mechanical Systems, vol. 7(2), pp. 902-913, 2014 | TUIL, ITA, FLANDERS |
| 7 | Pennycott, A., De Novellis, L., Gruber, P., Sorniotti, A. **'Sources of Energy Loss during Torque-Vectoring for Fully Electric Vehicles'** | International Journal of Vehicle Design, 2014 [in press] | SURREY |
| 8 | Goggia, T., Sorniotti, A., De Novellis, L., Ferrara, A., Gruber, P., Theunissen, J., Steenbeke, D., Knauder, B., Zehetner, J. **'Integral Sliding Mode for the Torque-Vectoring Control of Fully Electric Vehicles: Theoretical Design and Experimental Assessment'** | IEEE Transactions on Vehicular Technology, 2014 [in press] | SURREY, FLANDERS, VIF |
| 9 | Knauder, B., Savitsli, D., Theunissen, J., De Novellis, L. **'Electric Torque Vectoring for Electric Vehicles'** | ATZelektronik worldwide Edition, no. 4, 2014 | VIF, TUIL, SURREY |
| 10 | Ivanov, V., Shyrokau, B., Savitski, D. **'A Survey of Traction Control and Anti-lock Braking Systems of Full Electric Vehicles'** | IEEE Transactions on Vehicular Technology [accepted] | TUIL |
| Selection of papers under review (with many other manuscripts currently in process) | | | |
| 11 | Savitski, D., Ivanov, V., Shyrokau, B., De Smet, J., Theunissen, J. **'Experimental Study on Continuous ABS Operation in Pure Regenerative Mode for Full Electric Vehicle'** | SAE International Journal of Passenger Cars – Mechanical Systems | TUIL, FLANDERS |

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| No. | Authors, Title | Journal | Partners |
|---|---|---|---|
| 12 | Savitski, D., Shyrokau, B., Ivanov, V. **'Base-Brake Functions of Electric Vehicle: Disturbance Compensation in Decoupled Brake System'** | International Journal of Vehicle Design | TUIL |
| 13 | Savitski, D., Ivanov, V., De Smet, J., Theunissen, J., Pütz, T. **'Experimental investigations on continuous regenerative anti-lock braking system of full electric vehicle'** | IEEE Transactions on Industrial Electronics | TUIL, FLANDERS, TRW |

# 3 Promotion and outreach activities

The promotion activities of the consortium follow the overall strategy developed in Work Package 8 aimed at the dissemination of all the results and outcomes (i) within the consortium, (ii) national and international research communities, and (iii) general public and media. The following activities aimed at promoting the communication between the research community and different clusters of the general public were performed during year 3 of the project:

1. "Transforming the performance of electric cars", Publication on news portal of University of Surrey, 06.08.2014; http://www.surrey.ac.uk/features/transforming-performance-electric-cars;
2. "Project in de kijker: E-VECTOORC update", Publication on news portal of Flanders' Drive, 16.05.2014; http://www.flandersdrive.be/nl/over-ons/nieuws/project-de-kijker-e-vectoorc-update;
3. "E-VECTOORC: Dynamische Auslegung des Fahrverhaltens für Elektrofahrzeuge", Publication at Virtual Vehicle Magazine, Nr. 118, III-2014; http://www.v2c2.at/fileadmin/user_upload/pdfs/VVM/VVM-18_Area-X_17-FINAL_MR.pdf;
4. "Alternative Antriebe für Premium-Fahrzeuge On- und Off-Road", Publication at Virtual Vehicle Magazine, Nr. 118, III-2014; http://www.v2c2.at/fileadmin/user_upload/pdfs/VVM/VVM-18_Area-X_17-FINAL_MR.pdf;

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5. "Flandern baut Elektromobilität aus", Publication on investment informational portal of the German Federal Ministry for Economic Affairs and Energy, 24.10.2013; http://www.gtai.de/GTAI/Navigation/DE/Trade/maerkte,did=900254.html;
6. "Essential Support for Fanders' Auto Industry", The European Times, 29.01.2014; http://www.european-times.com/sector/flanders-drive/;
7. Presentation of the project on Joint EC / European Green Cars Initiative Workshop, 23.10.2013, Brussel, Belgium; http://www.egvi.eu/calendar/5/47/Joint-EC-European-Green-Cars-Initiative-Workshop-October-2013;
8. Introduction of the project on the European Nanoelectronics Forum and Exhibition, 27-28.11. 2013, Barcelona, Spain. The E-VECTOORC
9. (The project will be summarised at the Automotive Electronic Systems Innovation Network Annual Conference at the University of Warwick, England on the 15th October 2014.)

It should be especially mentioned that the E-VECTOORC project was awarded with the 3rd Place Exhibition Award during the European Nanoelectronics Forum 2013 in Barcelona (see Figure 1).


Figure 1 - E-VECTOORC Project Coordinator Dr Aldo Sorniotti at the Award Ceremony of the European Nanoelectronics Forum and Exhibition, 27-28.11. 2013, Barcelona, Spain

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# 4 Engagement with stakeholders

The E-VECTOORC consortium was and is in direct contact with governmental, industrial, academic and relevant non-profit organizations identified as the potential stakeholders. The stakeholders have the benefit of obtaining first-hand information of the project results and are able to contribute comments on the project findings. The most important actions in this connection were:

- E-VECTOORC Special Session at the FISITA 2014 World Automotive Congress at Maastricht (The Netherlands), 4.06.2014
- E-VECTOORC final dissemination workshop, which took place on 28.08.2014 at the Heritage Motor Centre at Gaydon (UK).

The E-VECTOORC Special Session at the 2014 FISITA Congress (Figure 2) focused on the latest project findings, including the results from the experimental activities with the E-VECTOORC vehicle demonstrator. About 40 engineers from industrial and academic sectors attended the session, which was opened by the project coordinator Dr Aldo Sorniotti. During the Special Session, the different consortium partners presented the latest project outcomes and discussed them with the audience. In particular, the following five presentations were delivered:

- “Electric vehicle capability”, presented by Phil Barber (Jaguar Land Rover)
- “Torque-vectoring control for fully electric vehicles”, presented by Leonardo De Novellis (University of Surrey)
- “Powertrain architecture of electric vehicles with individually controlled switched reluctance motors”, presented by Johan Theunissen (Flanders‘ Drive)
- “Active vibration control for torsional oscillations in powertrains for fully electric vehicles”, presented by Javier Orús (Instituto Tecnologico de Aragon)
- “Electric and friction braking control systems for AWD electric vehicles”, presented by Thomas Pütz (TRW Automotive) and Dzmitry Savitski (Ilmenau University of Technology)

In addition to the Special Session, the E-VECTOORC vehicle demonstrator was exhibited at the FISITA Congress.

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**Figure 2** - E-VECTOORC Special Session at the 2014 FISITA World Automotive Congress. Left top: Dr Sorniotti, Dr De Novellis (University of Surrey); Right top: Mr Theunissen (Flanders' Drive); Left bottom: E-VECTOORC vehicle demonstrator; Right bottom: Mr Orús (Instituto Tecnologico de Aragon)

The E-VECTOORC final dissemination workshop (Figure 3 and Figure 4) at the Heritage Motor Centre (Gaydon, UK) was designed to present the final experimental results obtained with the vehicle demonstrator and to highlight the overall project achievements. The workshop programme lead to for very fruitful discussions with the invited experts and stakeholders. In detail, the workshop included the following presentations:

- „E-VECTOORC project and objectives overview", presented by Aldo Sorniotti (University of Surrey)
- „Vehicle requirements, architecture and build", presented by Dirk Steenbeke (Flanders' Drive)
- „Switched reluctance motors", presented by John De Clercq, Kevin Verhaege (Inverto)
- „EMC testing for fully electric vehicles", presented by Fernando Arteche (ITA)
- "Functional safety for fully electric vehicles", presented by Yoann Descas and Johan Theunissen (Flanders' Drive)

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- "Direct yaw moment controller: objectives, comparisons and experimental results", presented by Aldo Sorniotti (University of Surrey) and Bernhard Knauder (VIF)
- "Friction brake system implemented on the vehicle demonstrator", presented by Thomas Pütz (TRW Automotive) and Dzmitry Savitski (Ilmenau University of Technology)
- "Torsional vibration control of on-board electric drivetrains", presented by Javier Orús (ITA)
- "Regenerative braking and longitudinal slip control using electric machines", presented by Dzmitry Savitski (Ilmenau University of Technology).


Figure 3 – Audience at the E-VECTOORC final dissemination workshop


Figure 4 – The vehicle demonstrator at the E-VECTOORC final dissemination workshop;

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Representatives of the following companies and research institutes attended the E-VECTOORC Final Dissemination Workshop:

- Alcon
- Cerulean Vinions Ltd
- Cranfield University
- DSD
- Hutchinson
- Leoni
- McLaren Automotive
- Millbrook
- Original Dynamic
- Phare-Tech Ltd
- Pi Innovo
- Protean Electric
- Punch Powertrain
- Richard Hurdwell Engineering Ltd
- Tata Motors European Technical Centre
- UK Ministry of Defence
- University of Bristol

# 5 Project collaboration activities

The E-VECTOORC consortium gives special attention to collaborations with relevant European, national and internal projects. Such mutually advantageous cooperation are being organised or are in preparation with the following projects:

- PORT: Powertrain – Radio Train. Interdisciplinary research group at Ilmenau University of Technology sponsored by Free State of Thuringia. Subject of collaboration: brake design for modular wheel corners of electric vehicles.
- iCOMPOSE: Integrated control of multiple-motor and multiple-storage fully electric vehicles. FP7 project started in October 2013 which is a synergetic extension of E-VECTOORC.
- PLUS-MOBY: Premium low-weight urban sustainable e-mobility. FP7 project started in October 2013. Through SURREY and CIDAUT collaborations are established related to vehicle control and energy management.

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- FREE-MOBY: People centric easy to implement e-mobility. Through SURREY potential collaboration on safety regulations is possible. CIDAUT establishes collaborations related to the testing of the vehicle demonstrator from an energy point of view.
- URBAN-EV: Super Light Architectures for Safe and Affordable Urban Electric Vehicle. FP7 project (Grant agreement no: 605634) started in October 2013. CIDAUT establishes collaborations related to the design, testing and validation of a 2-seat urban electric vehicle with considerably enhanced autonomy.
- National project of Czech Republic No. TA04031769 (07/2014 - 06/2017) SKODA establish synergies on the development of an adaptive interactive system for increasing safety of vehicle crew and its use for evaluation of pavement surface characteristics.
- EVOQUE-E: the JLR led consortium will design, develop and build research vehicles showcasing next-generation power-train concepts for a 'mild' hybrid electric vehicle, a plug-in hybrid and an electric-battery vehicle. The project started in October 2013.

# 6 Patent applications

The functional validation of the main E-VECTOORC controllers in laboratory and road conditions has allowed to prepare three patent applications, which are submitted to the German patent office:

- "Integrated traction and brake torque control method and control device for electric vehicles", in cooperation between TUIL, ITA and FLANDERS
- "Apparatus and method for disturbances compensation through decoupled wheel torque control in electric vehicles", application of TUIL
- "Apparatus and method for desensitization of traction control and anti-lock braking systems for electric vehicle in rough road conditions", in cooperation between TUIL, JLR and SURREY.

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# 7 Conclusions

1. The project is recorded in a highly accessible website www.e-vectoorc.eu
2. The project has been actively disseminated to the wider public audience at a number of events, and further publicity is planned.
3. The results from the project have been exploited internally to each of the partner's organisations and the work carried forward into ongoing projects related to the original aims of E-VECTOORC.