1. PUBLISHABLE SUMMARY

List of Beneficiaries

Beneficiary Number	Beneficiary name	Beneficiary short name	Country
1 (Coordinator)	Centro de Estudios e Investigaciones Técnicas	CEIT	Spain
2	YORK EMC SERVICES (2007) LIMITED	Y-EMC	UK
3	IDIADA AUTOMOTIVE TECHNOLOGY SA	IDIADA	Spain
4	TEKNOLOGIAN TUTKIMUSKESKUS VTT	VTT	Finland
5	Politecnico di Milano	POLIMI	Italy
6	MIRA LTD	MIRA	UK
7	JEMA ENERGY SA	JEMA	Spain

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Summary description of project objectives

Nowadays, road transport relies almost exclusively on fossil fuels. In fact, road transport is responsible for one-fifth of the EU's total emissions of carbon dioxide, and these emissions have increased by 26% since 1990. Thus, to achieve the 2020 target of reducing energy consumption and CO2 emissions, Fully Electric Vehicles (FEVs) need to reach a significant market share. Progress towards mass production of FEVs presents vehicle manufacturers with new challenges due to the relative immaturity of the new technologies that are involved. The most notable of these is the electric powertrain, comprising the electric traction machine and its associated power electronics.

One of the main objectives of the HEMIS project is therefore to design an in-vehicle Prognostic Health Monitoring System (PHMS) for the powertrain in order to enhance the safety and maintainability of FEVs. This system will be able to analyze the failsafe state of the powertrain by monitoring selected physical characteristics. It will also estimate its remaining useful life (RUL), and which component will fail first, thus enabling a predictive maintenance policy.

The HEMIS project has a second main objective. The electromagnetic fields emitted by the electric powertrain and their possible effects on the human body, as well as any interference with other systems on the vehicle, have been analyzed. It has then been assessed whether these fields, which may differ from those in a conventional car, can exceed current standards. For that case, HEMIS project proposes to recommend adaptations to the automotive standards so that the electromagnetic field is always below acceptable limits.

The main objectives of the HEMIS project are divided into the sub-objectives specified below:

O.1 Define a generic architecture for the FEV and undertake hazard and RAMS (Reliability, Availability, Maintainability and Safety) analysis.

O.2 Improve the knowledge of failure mechanisms, identifying the most critical ones, and asses which physical magnitudes are the best to monitor the powertrain failsafe state considering the reliability, accuracy, cost and feasibility of integration into FEVs.

O.3 Integrate hybrid information into prognostic algorithms to estimate a RUL value.

O.4 Design, develop and test a prognostic health monitoring system for the powertrain of electric vehicles (PHMS).

O.5 Identify limitations of current legislative requirements regarding electromagnetic fields (EMF) from FEVs and propose Electromagnetic Compatibility (EMC) testing methods to standards bodies.

O.6 Study the relationship between low frequency emissions and the current density induced in the occupants in order to propose reference levels for in-vehicle human exposure to EMF.

Work performed and main results achieved

The HEMIS project is broken down into eight work packages (WPs) that will lead to the completion of the ultimate goals of the project. All the tasks for the period from 1st June 2014 to 28th February 2015, described in Annex I (Description of Work dated 14/04/2014) have been completed as planned. The following activities were performed during this period:

WP1: Coordination and management

During the second review meeting some information updates were requested by the EC related with WP1, WP2, WP4 and WP5. The corresponding deliverables were resubmitted during this period, being these changes detailed in section 2.3. Related with the third period of the project, some budget has been transferred from Y-EMC to CEIT and POLIMI. All the deliverables and milestones for the period from 1st June 2014 to 28th February 2015 described in Annex I dated 14/04/2014, have been achieved.

WP2: PHA and RAMS apportionment of the FEV

This work package finished in the first period and was devoted to the definition of a generic FEV architecture and the RAMS analysis and apportionment.

WP3: Identification of the causes of degradation of the motor and the control, and their consequences

This work package finished in the first period and was devoted to analyse the causes of degradation for the powertrain, as well as their effects and criticality.

WP4: Monitoring of the physical characteristics of the motor and control and prediction of their RUL

The aims of this work package are to identify which physical characteristics are most appropriate to monitor the performance of the powertrain and to define prognostic algorithms able to estimate the powertrain's remaining useful life. During the first two periods of the project the most relevant failure modes of the powertrain and the corresponding monitoring variables were identified and most of the prognostic algorithms were developed. During the third period, this WP has been extended with the following objectives:

- The further development of the algorithms devoted to stator windings and IGBTs monitoring.
- The tuning of algorithms' parameters for the selected powertrain components, so that the associated estimation uncertainty can be reduced.

- The validation of the algorithms' results based on the measurements provided by the PHMS sensor boards.

WP5: Analysis and measurement of EMC characteristics and health impact of EMF

This work package is devoted to the assessment of the electromagnetic field emitted by the electric powertrain on EMC issues and on the occupants. During the first two periods, emissions from traction motors were measured and compared with ICNIRP exposure guidelines, and the impact of such emissions in human body was assessed through simulations. In the third period, the EMF emitted by a fully electric vehicle using the SR powertrain measured in the second period has been measured at the vehicle manufacturer premises. The results have been reported as an annex in a new version of D5.2.

WP6: Identification of hazard limits and design and implementation of on-board monitoring systems

This work package is devoted to the design, development and testing of the monitoring systems for the powertrain subsystems. During the previous period, a distributed structure was proposed after discussion with the Industrial Advisory Board. In this architecture, a central electronic board executes the algorithms defined in WP4, and some Satellite systems (specific for control, motor or EMC) collect the data needed by the former. All modules are connected by a CAN network.

During this period, the work has been focused on validating the Satellites developed during the previous period. In this process, some limitations of the Satellite were detected and solved. For example: the microcontroller in the Motor Satellite has been changed because higher features were needed for processing sensor signals and transmitting CAN messages at the same time. Besides, the sensor boards of the Control Satellite have been modified in order to improve the quality of the signal to be processed by the microcontroller board. After this modification, the algorithms outcome has been satisfactorily tested with data provided by the sensor boards.

Additionally, some differences between the Satellites CAN protocol implementations were detected during the WP7 test bench development. Modifications were carried out during this period to implement a uniform CAN communications in the three Satellites.

In this period, the magnetic fields that vehicle traction currents may create in close proximity to the cables and in the passenger compartment have been simulated, for a few representative vehicle scenarios. It was concluded that different sensor locations, as well as vehicle materials and constructions, would lead to different requirements for signal processing and initial "calibration" against magnetic field measurements in the passenger compartment, with the result that the process would be unique to each vehicle model. These results have been documented in deliverable D6.3. A new version of deliverable D6.1, with further focus on electric vehicles, has also been released.

WP7: Verification of the on-board monitoring systems for the fail safe transition

This work package is devoted to integrate the prototype of the on-board monitoring system and to verify it by means of a test setup. During this period the EMC Satellite has been developed, as well as the PHMS Central board. The latter reads the information sent by the three PHMS Satellites (for motor, control and EMF monitoring) and runs the prognostic algorithms, informing the vehicle about the powertrain condition and Remaining Useful Life. Four out of five of the prognostic algorithms have been ported to C Code and deployed in a microcontroller thanks to the collaboration between partners in WP4 and WP7. The fifth algorithm, in its turn, has been ported to a standalone application due to the complexity associated to the used of recursive functions in prognostic algorithm.

Regarding PHMS verification, two types of test benches have been proposed and developed. The first one is devoted to PHMS verification using real powertrains with degraded components. In this sense, several traction motors, capacitors and IGBTs, different from the ones used for algorithm development and tuning, have been degraded for PHMS verification. The second test bench is a Hardware-in–the-Loop system devoted to run some test cases which are either

dangerous/destructive or impossible to be carried out in real time (such as the emulation of capacitors degradation during a journey). It is also valuable to compare different versions of the PHMS with the same experimental data.

The performance of prognostic algorithms has been assessed with data obtained by the PHMS sensor boards, with satisfactory results for the monitoring algorithms for: PMSM, bearings, capacitor and IGBTs. As for the windings monitoring algorithm, the results obtained with experimental data were unsatisfactory. Finally, three monitoring algorithms ported to C code have been deployed in the Central PHMS and tested. Capacitor and bearings monitoring algorithm offered satisfactory results, while it was concluded that the data sent by Motor Satellite for PMSM should be bigger than initially expected.

WP8: Dissemination and exploitation

This work package focuses on the dissemination of the R&D results of the project. The dissemination was implemented through the following activities: web page, contributing to courses and conferences, meetings with stakeholders and a workshop with the industrial advisory panel.

Besides, a business plan has been discussed and developed, in order to exploit the results of the research carried out in the HEMIS project.

Expected final results

The **first outcome** of the project is a prototype of an in-vehicle prognostic health monitoring system for the powertrain, comprising the electric traction machine and its associated power electronics. This system provides information on the failsafe state of the electric powertrain and enables to apply a condition based maintenance policy on its subsystems.

The **second outcome** of the project is the proposal of design guidelines with mitigation techniques regarding electromagnetic compatibility and the impact of electromagnetic fields on human health; as well as low frequency emissions testing methods. This information was submitted and handled to standardization bodies and manufacturers of FEVs during the second period, and updated during third period based on further focus on FEVs.

Potential impact and use

HEMIS will contribute to increase the reliability of FEVs by analysing the failure modes of new building blocks, such as traction electrical motors and the associated power electronics. Moreover, the safety of FEVs will be significantly improved by means of the PHMS, able to detect the failsafe state of the FEV's electric powertrain. This could be used both to trigger safety automatic actions and/or to warn the driver about the failsafe state of the vehicle.

Besides, the RAMS analysis developed in HEMIS will improve the FEV design. In this sense, FEVs' manufacturers have been provided with information about the major contributors to the degradation of the powertrain, as well as with design guidelines on EMC issues. This way, HEMIS will strengthen Europe's position in existing markets, such as automotive industry, on-board monitoring systems and predictive maintenance.

Moreover, the PHMS predicts the remaining useful life of the subsystems analysed, thus aiding to the decision on when maintenance actions should be performed. Hence, maintenance costs will be reduced, while additional services are provided to FEV users.

Project logo and website

http://www.hemis-eu.org/