METHODS AND PROCEDURES FOR TESTING THE E-CALL IN-VEHICLE UNIT FOR THE PURPOSE OF ITS PERFORMANCE ASSESSMENT AND CERTIFICATION

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ABSTRACT

The main idea behind the pan-European eCall project is to automate the emergency call that is simultaneously extended by a message containing information such as current position and prior-to-crash speed, type of vehicle, VIN, VRN, number of passengers travelling, etc. The in-vehicle unit consists of measurement, communication, positioning and user-interface sub-systems, and all those sub-systems need to pass functional and performance type examinations before the device can be granted formal approval from the notified laboratory. The usual way of testing the module will be during the type approval of the car, as performance of the unit is strongly correlated to the dynamical parameters of the vehicle body and fitting procedures.

Technology of today makes it relatively easy and straightforward to measure linear and angular accelerations of the vehicle chassis to estimate its full state in the 6DOF space, however, the number of sensors required and resulting cost is mostly prohibitive, thus in practical solutions the crash detection is to be implemented based on signals acquired from a limited number of available sensors, preferably already present in the existing set-up, using also additional sources of data, such as longitudinal velocity from the speed sensor.

The purpose of the project is to design a testing methodology and set-up a testing bench for the type certification of the in-vehicle e-Call system units for the accredited laboratory. The test stand should allow the production of precise and repeated predefined testing conditions to excite the device-under-test sensors and to relate their logged data and results to those of reference set of sensors built-in to the test stand.

Another question we address during the study is the feasibility of data gathered in the in-vehicle e-Call unit for the purpose of reconstructing the crash.

INTRODUCTION

Within the framework of e-safety programme, a European Union initiative [3,9,15], eCall system is currently being implemented, which will decisively improve the process of road accident notification in the EU area. A few years ago, a need to introduce a uniformed emergency call number 112 across the EU territory was recognised by European legislation. The number is supposed to be operated with the same efficiency and effectiveness as the other traditional emergency numbers in each member state. Moreover, the personnel of the emergency call centre should be able to accept notifications in more than one language [1,4,16,18].

However, technical evolution has lead to further modifications of emergency call number 112, due to the development of new functionally extended version of the emergency call system named E112 (location-Enhanced 112), which will enable the emergency centre to automatically determine the location of the caller. This new feature of the technology is particularly important for people being abroad since the victims of the accidents often cannot precisely describe their current location and the time in emergency situations often means the difference between life and death.

The eCall system is another stage in the development of E112 technology. It assumes, the vehicles would be equipped during the production process with emergency sensors and communication modules, which, if the predefined emergency conditions are registered, will automatically dial the emergency centre and convey exact information regarding place of the accident, vehicle identification (registration number and VIN), its type as well as initiate the voice connection allowing the call centre personnel to gather additional data on the accident details, therefore, reaching optimal decision as to the parameters of the rescue operation.

Organisation of the eCall system

The eCall system consists of three main subsystems, which should be adequately designed and compatible in order to allow their interoperability and functionality.

The first main element of the system consists of emergency sensors – devices installed in the vehicle – containing a set of inertial sensors which detect excessive linear and angular acceleration values (breaking deceleration, impact into the obstacle or another vehicle) which allow detection of the accident, GPS module determining geographical position of the vehicle, direction and speed of its movement shortly before the accident, and GSM module to automatically or manually initiate dialling sequence to Public Safety Answering Point (PSAP).

The other element of the eCall system is the ground telecommunication infrastructure of the GSM operator as well as the ground and space infrastructure of satellite navigation systems. The infrastructure of GSM operators should allow dialling of emergency module installed in the vehicle also outside native mobile operator. The roaming should be available not only outside country borders in which the vehicle is registered and where the SIM card was issued, but also in the territory of the country of the origin, especially when the accident took place outside the coverage of a native mobile operator or when the position of the vehicle after the accident does not allow connection to the native operator whose signal in the given location is weak and in particular conditions, i.e. when the vehicle is turned over and the GSM antenna is shielded by its body and/or local topographical conditions in which case, the propagation of radio waves is heavily limited and the use of another mobile network, that provides stronger signal is possible. At the current stage of works on the subject, the decision has not been reached yet, whether the SIM cards are to be installed in the vehicles or not. If the SIM cards were not to be used, a European wide harmonisation of regulations would be required in order to allow emergency notifications without the possibility of identification of the caller [4,16]

In order for the notifications generated automatically by eCall modules or those initiated manually to take effect, the PSAP centres must be equipped with appropriate technical means that would allow receiving emergency information, its efficient verification and processing as well as effective management of rescue resources.

Technical requirements – eCall car module

The device installed in the vehicles according to the specification in the working documents [1,2,5,18] of the expert bodies of European Commission, must perform the following functions:

- if the accident occurs, it should automatically decide (after predefined criteria of accident are satisfied) whether to initiate dialling sequence with emergency number 112,
- the system should provide possibility of manual initiation of dialling to PSAP centres with the use of easily accessible user interface; this implies the device should be equipped with button/keyboard to initiate dialling, its cancellation if activation is accidental as well as indicators of connection state (initiation, cancelling),
- the system should also allow sending the Minimum Set of Data required, which would identify the vehicle and circumstances of accident occurrence.
- initiation of the voice connection when dialling the emergency number 112 should be allowed.

At the current stage of works within the expert groups, a decision whether to install additional independent GSM modules with the emergency sensors in the vehicles or if to allow the use of mobile phones and SIM cards owned by driver/passengers has not been finally reached yet. From the technical point of view, the second choice is possible, from the economic perspective it seems even more plausible since it would decrease the general costs of the system introduction. However, there are also significant technical disadvantages of this solution, which very likely will eventually cause its rejection.

The built-in GPS module allows the read out of current parameters of motion (geographical location, value and direction of speed) and it is required to transfer data on speed and direction of movement from the last three validly determined positions. In the communication protocol it was also agreed that the information on the quality of the determined position is to be transferred in order to estimate statistical uncertainty of the rescue calculated position.

Satellite navigation systems – GPS, Galileo, GLONASS

Currently, GPS (Global Positioning System) is the only fully functional system of satellite navigation, which was designed and constructed and is run by US Department of Defence in the framework of NAVSTAR programme.

Theoretically, as soon as in 1996, the full functionality of Russian system GLONOSS was announced, however, at the moment the number of working satellites in the orbit is less than the nominal 24, therefore, the system does not allow determination of position in any given time or area. In the worst period for the system (November 2001) due to the short life of the satellites, only six satellites were functional rendering the whole system useless. Now, the system consists of dozen or so of space vehicles located in two out of three planned orbits and there are plans to rebuilt the system to its full potential in the future.[18]

The third satellite navigation system, currently under development, is Galileo system. It is European project, financed by EU, being designed exclusively for civilian purposes (the other two systems depend on military structures, respectively of the US and Russia). The project also includes participants from outside EU, namely China, India, Israel, Morocco and Ukraine who have their share in co-financing. The future of the system as well as its completion date are still being hotly debated among its participants and regard mostly its financing and division of expected profits from its operation.

For the last few years there are plans to build a worldwide satellite navigation system GNSS (Global Navigation Satellite System), which would under the control of independent international organisation. Accession to the project was declared by the multitude of countries, including USA, Russia and EU member countries. During the first stage of GNSS development, the existing navigation systems are to be utilised, however, ultimately a completely new system of satellite navigation is to be constructed [9].

Every satellite navigation system consists of three segments: the ground segment, the orbitting vehicles and receivers which position is determined by receiver firmware. Currently, all of the systems in operation support passive receivers which means the user’s receiver can calculate its own position, time as well as direction and velocity of the movement, based on the signals obtained from visible satellites only. In order to determine position it is vital to be able to receive navigational message from at least four satellites. The accuracy of positioning depends on many factors, among others, the number of visible satellites, their relative positions in the orbit and signal disruptions on the way from satellite to the receiver (these interferences are a result of refraction in the ionosphere, troposphere and multipath distortions of signal – receiving signals indirectly from satellites, reflected from various obstacles and object in the vicinity of the receiver).

Table 1.
Comparison of satellite navigation systems accuracy [7,9]

Parameter	Satellite Navigation Systems		
	GPS	GLONASS	Galileo
Accuracy of horizontal positioning (95%)	100m (with SA distortion) 13-36m (without SA distortion) 3,7m (after modernisation - GPSIII)	30-40 m (50-70m according to spec.)	15/4 m ≤0,8-7 m
Accuracy of vertical positioning (95%)	300m (with SA distortion) 22-77m (without SA distortion) 7m (after modernisation - GPSIII)	60-80 m (70m according to spec.)	35/8 m ≤1-15 m
Accuracy of determining speed (95%)	≤2m/s	-	20cm/s - 50cm/s
Time (95%)	340ns	1 µs	50/30 ns

All of the currently existing and planned satellite navigation systems provide free of charge and unlimited access to public services, on the assumption that determining of the position is done automatically by the navigation receiver. In case of the augmented navigation systems, when the calculation of the position of the given receiver is done externally and sent back to the user or corrective data indispensable for differential GPS is sent, such services may be payable.

The satellite navigation system enables its operators to selectively turn off public availability of the service (e.g. in the area of warfare), while providing unchanged accuracy of dedicated services to authorised users (i.e. military users). Due to the nature and importance of satellite navigation in the course of military activities, the systems are assessed as to their susceptibility to deliberate distortion of signals which is to disrupt the regular system use or to falsify its readings.

For the purpose of using satellite navigation in eCall system, the following features of the existing and planned systems seems vital: general accessibility of positioning services in the analysed area regarding both the geographical location and time (how often and for how long the service may be unavailable), accuracy of determining location, speed and time, sensitivity of the receivers regarding the strength of signal which translates into using the system in difficult conditions: in urban areas, in mountains and forests (e.g. between high buildings, in valleys, under trees the visibility of satellites is limited and so is the possibility of receiving the signal). Further technological development of the space segment of the navigation system (i.e. increase of strength of emitted navigation signals, more active satellites in the orbit, improved orbit models) as well as development of the receivers (new constructions of the antennas, increase of their sensitivity, improved algorithms for elimination of signal distortions) will allow in the near future to improve functional parameters of receivers, more accurate positioning also inside buildings, in the areas of intense vegetation or diverse topographical features.

In case of eCall system, the sensibility of the receiver may be of vital importance for determining the position of the vehicle after the accident, in particular, when the vehicle after the accident is turned over or under construction elements (bridge, flyover). However, the system assumes the constant work of the receiver and requires to send the three last correctly determined positions of the vehicle including the direction and speed. Therefore, in case of the unfavourable conditions it should be possible to send sufficient information regarding the place of the accident and position of the vehicle. Obviously this possibility depends on the GSM network signal availability.

In-vehicle unit eCall positioning sub-system testing

For the purpose of verification of the vehicle unit fitted into particular car under test set of procedures, devices and designated software has been developed. Two identical GPS sensors have been connected (fig.1) to the recorder (fig.2) which simultaneously records all the GPS data produced by the sensors. Using two independent sensors of known sensitivity, mounted on the top of the car is assumed to deliver reference level of possible signal reception in particular conditions during the test. If the signal is not available to branded GPS sensors fixed to the roof of the car, outside of its metal chassis, the technical feasibility of producing a high quality solution, i.e. characterised by low HDOP/VDOP/PDOP parameters, by in-vehicle unit shall not be overestimated. The prototype recorder capable of logging GPS and IMU (inertial measurement unit) data is depicted in figures 1 and 2. The data is recorded on a SD/MMC card, thus available capacity is sufficient and available memory space can be easily expanded if necessary.

Figure 1. The reference GPS sensors in set-up designed for verification of statistical robustness of the positioning subsystem of the in-vehicle eCall unit.

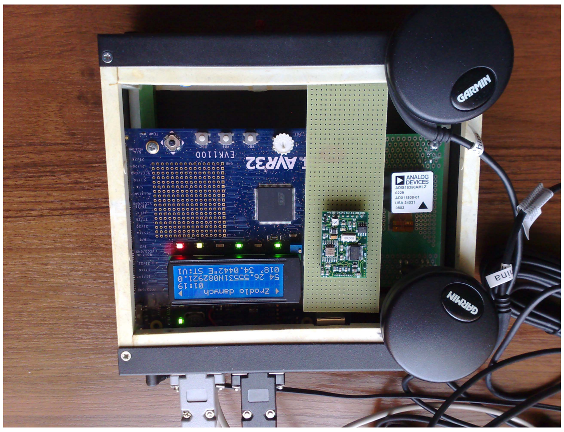

Figure 2. On-trip recorder designed for logging data from reference inertial measurement unit and two reference GPS sensors

To record the motion parameters of the vehicle output data stream of inertial measurement unit is used. In the prototype logger 6-DOF ADIS16350 has been utilised (fig.3) to produce reference stream of data to be compared with the eCall unit logged data. Data from the GPS sensors alone (both embedded in the eCall unit under test as well as in the reference sensor set) cannot be used for the purpose of attitude and trajectory determination for many different reasons, limited sample rate and continuity of signal availability among the most obvious ones, to list just two of them. In general raw data logged in in-vehicle eCall recorder cannot be easily used to retrace the vehicle trajectory. However combined information gathered from IMU and GPS can be seen as complete and sufficient to calculate the position and attitude, there are no legal requirements to facilitate in the eCall on-board unit algorithms to estimate the current parameters of the vehicle spatial attitude and heading, and without prior knowledge of used sensor parameters and performance it is generally impossible to reconstruct precisely the vehicle chassis trajectory, due to uncertain boundary conditions, unknown sensor stochastic noise parameters, and vehicle body dynamics. All the named information and noise characteristic of measurement channels and sensors is necessary to design a precise Kalman filter algorithm, the most commonly used family of algorithms to solve the problem of data fusion and processing of noisy, real-life data [6,7,8,14].

During the certification process it is to be manufacturer role to demonstrate how to use registered data to retrace the accident course, if claimed possible, or required by binding legal specification of minimal set of parameters and functional features of future eCall in-vehicle unit. The data registered by the reference tool is to verify the claim and to asses the precision of data and signals produced by eCall unit under test.

Figure 3. 6-DOF reference inertial measurement unit ADIS16350

The ADIS16350 inertial measurement unit is a 6-DOF sensor which consists of tri-axis (fig.3) accelerometers (+/-10g measurement range) and tri-axis gyroscopes (up to 300 deg/s digitally adjusted measurement range), producing data of 14-bit resolution in each measurement channel. The bandwidth of 350Hz, digitally controlled bias calibration, sample rate and filtering, with embedded temperature sensor sum up to a very convenient solution for motion control and analysis applications. If during the course of experiments the necessity of higher precision of measurement of accelerations emerge, there are compatible inertial measurement units available and tested in the set-up, featuring higher precision at the expense of a lower acceleration range.

GPS sensor sensitivity and performance assessment

In order to test statistical quality of the signals received by GPS sensors, data collected during the relatively long trip was evaluated statistically. In figure 4 there are showed short periods of precision parameters logged during the trip depicted in fig. 5. The VDOP, HDOP, PDOP (Vertical-, Horizontal-, Position Dilution of Precision) strongly correlate with the current number of satellites used in the fix.

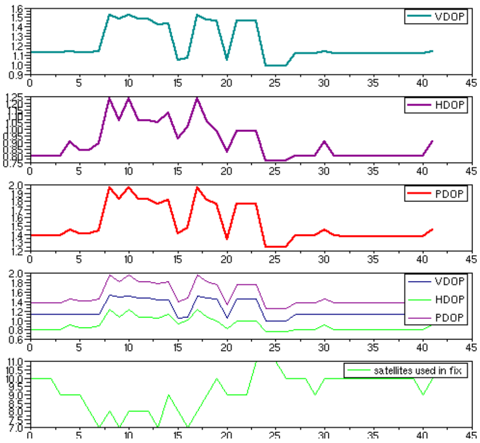

Figure 4. Quality of the GPS solution differs with current local conditions, with main factor being the number of available satellites used in the fix.

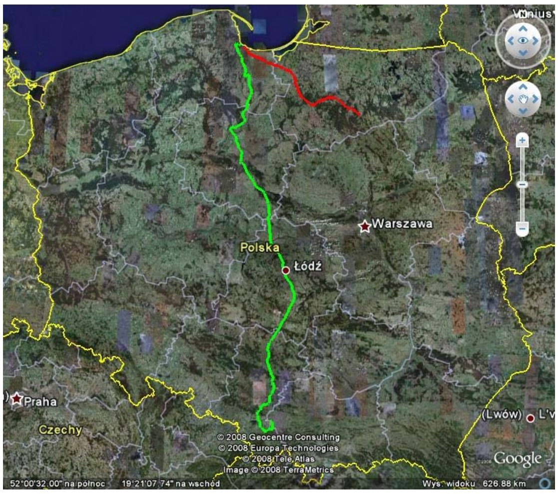

Figure 5. Two example registrations taken with the trip logger to gather data for statistical analysis referred to in the text and the following diagrams.

The higher the number, the more precise the navigational solution, however it depends also on the relative position of space vehicles used in the solution. In order to obtain good quality of the solution from minimal number of satellites, they had to be uniformly dispersed in the orbit, from the observer/receiver standpoint. Diagrams presented in fig. 6 depict histograms of satellite number used in solution during the test trip and related histograms of PDOP. Pairs of diagrams present data collected on the same route – upper two diagrams Southbound trip, and the lower two on the way back, Northbound. On the way Southwards most of the time eight or nine satellites were present and used in the fix, with considerable fraction of time when ten and eleven satellites available. On the way Northwards even better coverage of GPS signal has been registered, as for over 60% of time there were nine and more satellites available, frequency almost evenly spread for nine, ten and eleven satellites. That produced good PDOP distribution, of the value of 1.0 for most of the time, and negligible frequency for PDOP values above 2. In figure 7 the example of mapping the logged data is presented. It can be easily noticed that due to inadequacy of freely available Google map service, or GPS precision issues, or both the precision in mapping easily can be lower than a few meters, which agrees well with technical specification.

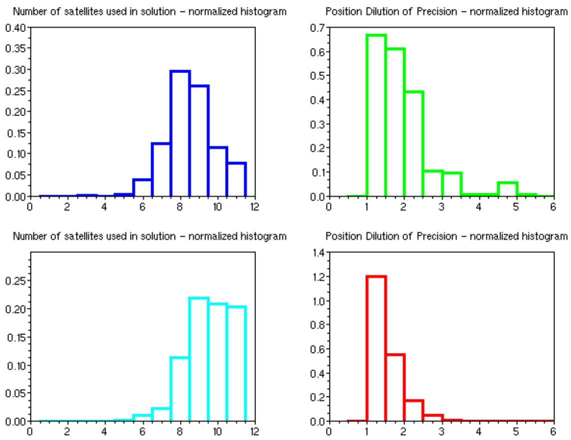

Figure 6. Histograms of satellite number and responding PDOP (Position Dilution of Precision).

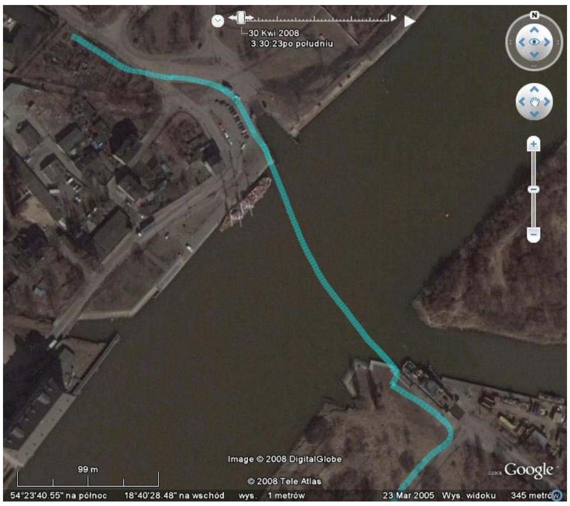

Figure 7. Example of inaccuracy of GPS mapping.

Figure 9. GPS logged data mapped in urban environment of low intensity

In figure 9 GPS signal was mapped on an aerial map, where again inaccuracy of a few meters is noticeable and repeatability of measurements far from ideal, even if the experiment was conducted in an urban area where no high buildings nor heavy vegetation were present. Additionally, there is tangible instability in GPS sensors read-out close to the final u-turn of the test ride, where bigger lost of precision has been observed. This demonstrates limit of potential trajectory reconstruction on the base of GPS output alone.

Data transmission

The basic difference between eCall system and E122 is the principle that the system should automatically detect the emergency event and send sufficient data to the PSAP centre. The data has to be transmitted on the main voice channel i.e. during the established connection with the operator. In the past, there were considered also other models of data transmission in GSM systems, such as GPRS or SMS. However, due to various reasons (reliability, limited accessibility, time required for connection different than voice connection in case of GPRS) these solutions were disqualified and currently the EU expert working groups consider the use of in-band modem technology or other similar systems of transmission at the beginning or during voice connection.

In the specification of the eCall car module there was defined the Minimum Set of Data (MSD) which the emergency sensor installed in the vehicle has to send in case of an accident. During the next development stage of eCall system it is expected the amount of data to be sent will increase and covey more information concerning the course and effects of the emergency event, which will influence the optimisation of the rescue operation. The additional data will concern number of passengers in the vehicle at the moment of the accident, the force of the impact, acceleration values, velocity change at the moment of the accident and thus it will allow estimation of the possible level of injuries. If these data and other will exceed 120 bites of MSD will be sent as Full Set of Data (FSD).

Certification of eCall system components

Certification of eCall system components is crucial, since their excessive sensibility (generation of false alarms) will cause the increase of the maintenance cost of the entire rescue system in EU. On the other hand, insufficient sensibility of the components will influence the whole system which will fail to meet the expectations as to diminishing the fatality rate of the road accidents.

Therefore, during the certification process, accuracy of sensor modules performance should be measured as well as their functionality in vehicles (do they meet the high technological criteria of the automotive industry). During these examinations it is necessary to measure the susceptibility of these devices to electromagnetic interferences, i.e. electromagnetic compatibility, as well as to measure their distortion emissions. What's more, the devices should undergo climatic research in order to determine their performance proprieties within the required temperature range i.e. -40 to +85°C.

The algorithms for emergency event detection should be assessed separately. In the first version of the documents announced to the public on EU web pages, the certification process was to be carried out by the producers of vehicles and realised based on the existing legislation regarding homologation of vehicles. However, currently, due to the recent arrangements, the independent suppliers may produce and install the sensors, therefore, a detailed technical specification is required, also test and research methods should be elaborated in order to be able to verify eCall modules.

Detection of the accident. Assessment of the potential injuries.

In order to detect accidents, there are used signals from available or specially installed linear acceleration sensors (accelerometers) and angular acceleration sensors (gyroscopes), magnetometers (compasses) but also from conventionally installed acceleration sensors in the vehicles. In most vehicles that are equipped with airbags, two-axis acceleration sensors are used to activate the bag, which allow determining e.g. delta velocity, that is commonly regarded as an effective estimator of potential accidents results.

Regrettably, having at your disposal the two-axis acceleration sensor does not allow outlining the full trajectory of vehicle movement, moreover there are justified doubts whether it will be possible to even detect the turnover of the vehicle. In accordance with the EU statistics [14] only 0.2% of vehicle sold in Europe is equipped with sensors determining turnover of the vehicle. Due to the cost of the essential devices (gyroscopes) which would have to be installed in each eCall sensor, at the current stage of research, in order to determine the position of the vehicle after the accident, only acceleration sensors are being considered when developing eCall system since they are already installed in the vehicles to initiate airbags.

Among potential applications of eCall, which directly result from the fact of registration and data collection regarding the accident, there is the attempt to use these data to reconstruct the course of the accident, identify its main causes and the guilt of the accident participants both in minor events and in case serious road catastrophe. The usefulness and reliability of collected data regarding reconstruction of the events should be the subject of further research and analysis. Other important issue is legislative aspects of the collected data use, who is their owner, who is allowed and in what way should access and analyse the data, can the vehicle owner reject data availability, what procedures should be used when the data is purposely destroyed, etc. Law enforcement bodies as well as insurers should definitely be interested in these data.

Testing the eCall module using vehicle model

To produce motion to excite both reference measurement system and the device under test a remotely controlled vehicle model has been adopted. The model (fig.10) previously used by authors for testing the “black-box” recorder [10] has been upgraded and equipped with new sensors and new control system to facilitate extensive tests of eCall in-vehicle module.

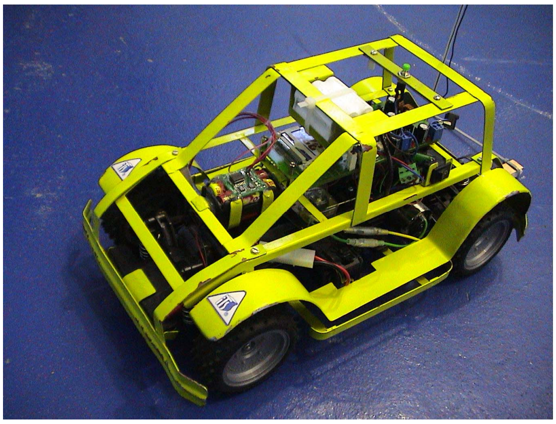

Figure 10 . Vehicle model

Previously the model was controlled by “classical” remote controller equipped with two potentiometric manipulators (one for speed and one for direction control), now the control on-board the model is effectuated by 32-bit Freescale micro-controller receiving commands via wireless Zigbee link from the PC based application. This allows to produce repeatable, pre-programmed control sequences, for instance designed as Scilab scripts, allowing for visualisation of data gathered during the tests. Optionally it is possible to use game console connected to the PC USB port to allow controlling of the model with the use of steering wheel, and accelerator and brake pedals. The model on-board controller is responsible for maintaining precise control over the model vehicle, i.e. close-loop algorithms ensure following precisely pre-programmed trajectory at pre-programmed vehicle velocity. All the motion parameters are logged in the model controller memory.

To produce higher velocities and to allow of testing of bigger and heavier eCall modules more robust and more powerful model driven by combustion engine also has been equipped with similar set of equipment, remote controller link and actuators.

The first couple of tests have been carried out without any eCall in-vehicle unit as there weren't any available for tests at the time of writing. Data was only registered in the reference data acquisition system. The electric-motor-driven car model was directed towards concave ramp to force a roll-over accident (fig.11). Only data from model IMU has been logged, no GPS sensor data was collected nor analysed, due to the fact that the experiment was conducted inside the building, the ride duration was considerably shorter and the reached velocities was tangibly lower than anticipated in the real-life conditions preceding an accident. However, the IMU registered data is expected to be relevant to real-life conditions, even at lower velocities, due to smaller dimensions and lower weight and moments of inertia of the model. Some data have been also logged on the real passenger cars, commercial good vehicles and coaches, to verify dynamics of registered signals, both on the models and real vehicles.

In following experiment the model has also been driven with marking its trace piece of chalk (fig.12), to allow to assess the reliability of collected data for the purpose of accident course reconstruction.

Figure 11. Selected consecutive video frames featuring a rollover

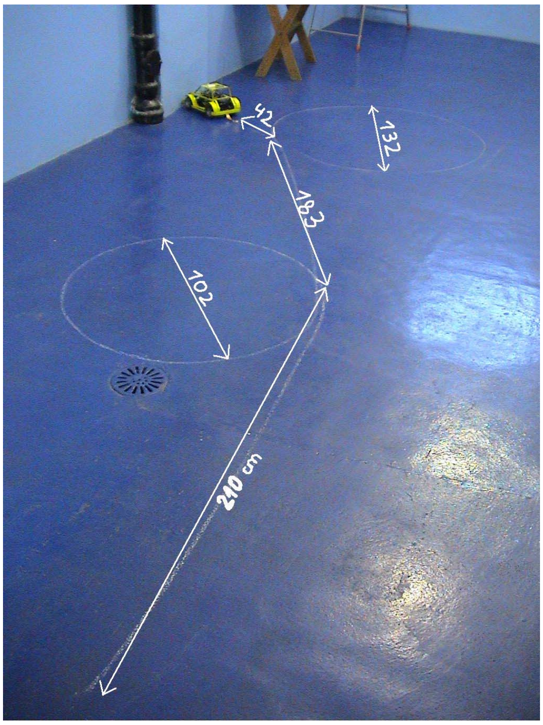

Figure 12. A trajectory reconstruction test

CONCLUSIONS

Many publications express the necessity of further research on accident detection and severity estimation algorithms, as deep understanding and wide availability of complete and robust solutions is far from satisfactory. In order to fully explore all possible benefits that can be brought by eCall implementation within the EU territory, not only well designed algorithms to detect the accident and estimate its severity are required, but also legal framework, methods and technical means to allow the formal authorisation of all the devices and systems (in-vehicle units, telecommunication and GNSS infrastructure and the public, emergency answering point network, both equipment and organisation performance). Without verification and certification before the legal approval is granted to introduce such devices to operation, if it leads to approval of devices producing false alarms or failing to recognise the actual accident, the chaos sparked by the eCall implementation could jeopardise all the hopes and expectations in reducing severity of injuries and number of fatalities.

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