Corporate Research

From	Our Reference	Tel	Renningen
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R&D Report: **Final Report**

Security Class: Confidential Export control relevant: No

Title: VM-156: Advanced Crash Detection for PTW eCall

Abstract

This report is the follow-up report of the “VM-156: Crash Detection for PTW eCall” report.

1. Issues (situation, motivation and tasks)

The VM-156 was the internal project dedicated to the public funded project (PFP) i_HeERO WP3, Infrastructure Harmonised eCall European Deployment, which started in 2016. The aim of the i_HeERO project is to derive the specific requirements for a powered two-wheeler (PTW) eCall system and in the end to give a proposal for standardization. The so far internally developed crash detection is a basic and rudimental algorithm which identified potential features and methods for the detection of critical situations. Nevertheless the basic algorithm did not achieve the requirements for a complete and reliable automated eCall system. This report deals with the further development of the crash detection algorithm right up to the integration of the system into a prototype.

2. Results

Based on the output of the i_HeERO proposal and internal requirements diverse verification tests were defined. Therefore the database of accidents and misuse cases was extended as well as the algorithm was extended accordingly to the requirements. Up to now the database consists of 812 files with 68 accidents and an overall test time of 200h. The most important improvements of the algorithm are speed dependent acceleration thresholds for the collision detection, the stand still detection to enable the exclude of uncritical topple at stand still from eCall launch and the monitoring of the gradient of the front wheel speed for front collisions against rigid objects. The improvements increased the detection rate up to 99.99% correct classified events of the database. Beside the algorithm development one of the main achievements of the second part of the project was the build-up of hardware prototypes. Therefore the algorithm was transferred into the ABS ECU software language ASCET and finally implemented in an Aprilia Tuono 1100 and KTM 1290 Super Adventure R, both equipped with the BOSCH ABS 9ME. Both prototypes were tested and presented to the project partners during the i_HeERO pre-test and main event at CR Renningen.

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3. Conclusions and Consequences

The algorithm and hardware prototypes showed a good performance on the test track as well as on the offline tests via sensor signals out of the database. The results are transferred to the 2WP business unit in E12/2017. The algorithm prototype has pre-development status. It is not ISO26262 conform and not developed according to ASIL-requirements. The series development will be done by the business unit. A field test with a fully equipped motorcycle in Q1/2018 is planned by the 2WP business unit.

The current algorithm is based on the MM5.10 IMU, due to the fact that this sensor will be replaced by the MM7.10 IMU in the next generation of motorcycle ABS systems, a comparative test of the sensors is suggested.

Document approval			
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Key Words
Crash detection, fall detection, PTW, eCall, MM5.10, i_HeERO, PC Crash, Multi Body Simulation

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Long Version

1. Issues (situation, motivation and tasks)

The VM-156 was the internal project dedicated to the public funded project (PFP) i_HeERO "Infrastructure Harmonised eCall European Deployment" with the WP3 "eCall powered two wheeled vehicles" which started in 2016. Part of the WP3.4 was to build up a complete eCall prototype on hardware and software level with the objective of online tests and presentation of the proposed minimum requirements and functions in different riding situations.

The developed basic crash detection algorithm needs improvements to fulfil the requirements of the proposed verification standard and of a robust eCall function. Therefore the concept of wheel speed sensor signals as additional input for different features has to be implemented and assessed. Robust concepts for detecting non-critical events like topple at stand still has to be developed and integrated into the algorithm structure. Furthermore the implementation of the crash detection algorithm into the ABS ECU hardware required the transfer of the algorithm into the development environment ASCET and finally an integration into the current ABS software structure.

Beside the crash detection itself a study of the feasibility of an injury severity estimation based on on-board sensors has to be performed as a task of the i_HeERO project. The results of the thesis are also given in this report. Further as part of the data acquisition and the injury severity estimation study an assessment of the potential use of the simulation tool PC Crash (by DSD) in combination with a multi body simulation add-on has to be done.

2. Results

2.1. System and Enabling Technology

As an output of the basic algorithm development and to fulfil the requirement of using as less additional hardware as possible on the bike, the target system is a current Bosch motorcycle ABS system. The minimum system setting is a Bosch ABS ECU in combination with the MM5.10

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inertial measurement unit (IMU) which is mainly used in ABS systems with traction control or in the Motorcycle Stability Control (MSC) for lean angle estimation. Figure 1 shows the KTM 1290 Super Adventure R eCall prototype including the original equipped ABS and IMU system (blue) as well as the additional hardware, the communication unit (CCU) and the eCall button (grey). The CCU und eCall button will be described in detail in chapter 2.5.

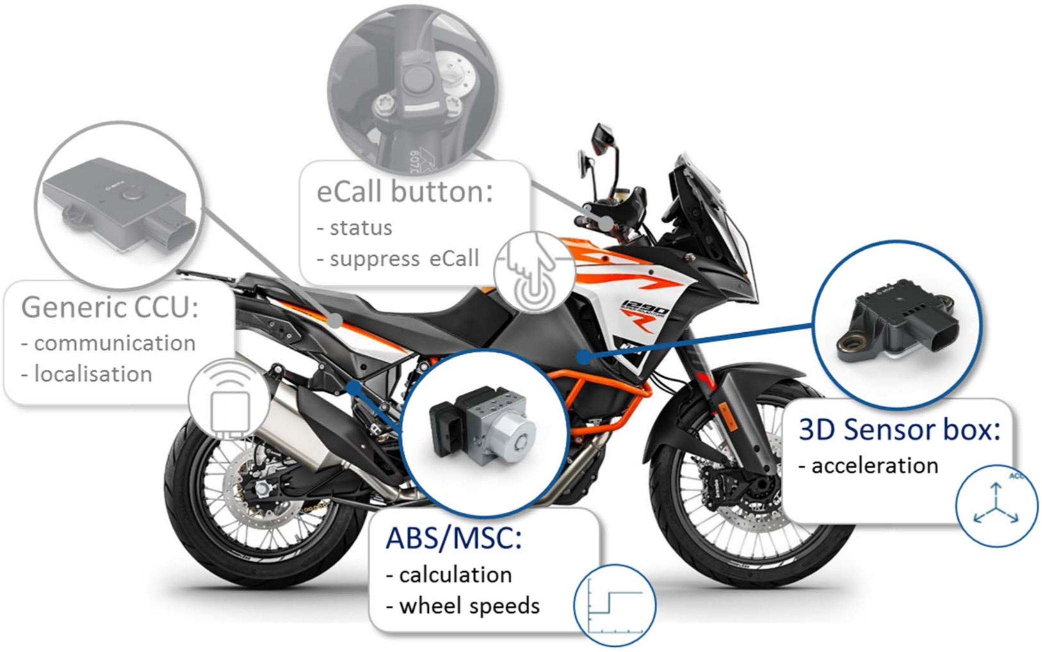

Figure 1: Minimum set of hardware (KTM 1290 Super Adventure)

2.2. Data Acquisition and Database

The present database with a collection of misuse cases and accidents was extended to a total number of 812 files (events as well as endurance runs) including 68 accidents with an overall length of around 200h. Of vital importance for further improvements of the algorithm are the additional data sets out of real tests on the proofing ground at CR Renningen and Boxberg and the test facility of DEKRA in Neumünster (GER) which cover the so far missing data or rather missing maneuver. The settings and the focus of each test series will be described in the following.

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2.2.1. Tests at CR Renningen Test Track

The focus of the test series on the proofing ground at CR Renningen was on collecting data of normal riding maneuvers with different types of motorcycles during acceleration, deceleration up to the intervention of the ABS system or the traction control. This was also tested in uphill and downhill situations.

Besides the riding maneuvers the second focus was on mishandling situations in the low speed rang like topple at stand still or hitting the wall in the garage. For this purpose the topple tests were also performed on the testing hill to reach the possible maximum loads of this test case by having a motorcycle that is toppling the hill downwards or which is forced to topple by hardly kicking it.

Figure 2: KTM 1290 Super Adventure R in topple tests

The test were performed with an Aprilia Tuono 1100 as representative of sport bikes and a KTM 1290 Super Adventure R as representative of a touring or off-road bike. The collected data contain a set of standard system signals available on the vehicle CAN.

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2.2.2. Tests at Boxberg Test Track

The purpose of the tests on the rough road tracks in Boxberg was on collecting data of different types of motorcycles on different road conditions. Therefore the different surfaces potholes, washboard, shake and vibration tracks, Belgian block tracks, stretches of road with varying surface levels were passed through with increasing speed level and as far as possible with varying the lean angle.

The tests were performed with an Aprilia Tuono 1100 as representative of sport bikes and a KTM 1190 Adventure as representative of a touring or off-road bike. The collected data contain a set of standard system signals available on the vehicle CAN of the Aprilia bike. Due to that fact that the KTM bike is the fully sensor equipped test bike of the CR, some more sensor signals are available like spring deflection or steering angle.

During the tests the Aprilia bike reached the limits of ridable rough road surfaces for sport bikes. Any further increasing of the test speed would finally lead to a high risk of accident. Therefore the reordered signals are potentially the maximum loads on a sporty bike which appear without a crash or what a rider would expose the bike.

Figure 3: Boxberg rough road track

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2.2.1. Crash Tests at DEKRA (Neumünster)

The so far performed crash tests covered most of the standard situations which occur in the general traffic. The focus of the second set of crash tests was on the extraordinary situations like collisions with a rigid wall or a trailer with the high risk of getting stuck upwards as final position. Therefore additional six crash tests were performed. The sensor setting was comparable to the first crash tests at DEKRA in CW1 of 2017. (see report "VM-156: Crash Detection for PTW eCall")

Sensors were mounted on the front fork and the center of gravity, each of the measuring points was equipped with a high-g crash sensor, a MM5.10 standard configuration and a MM5.10 sensor with extended range. Additionally the center of gravity was equipped with a 3D sensor for the angular velocity. Further the wheel speed signals as well as the dummy loads were recorded during all tests. Figure 4 shows the sensor setting of the crash bike followed by Figure 5 which shows the final position of the bike and dummy after the 40kph collision against a trailer underride barrier.

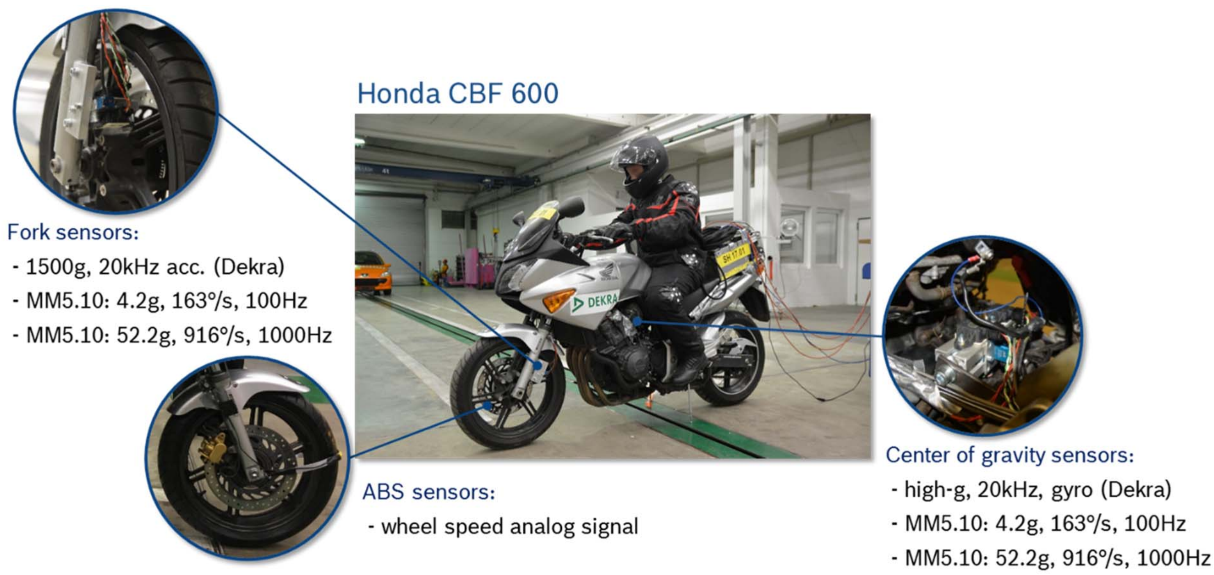

Figure 4: Sensor setting of the crash bike

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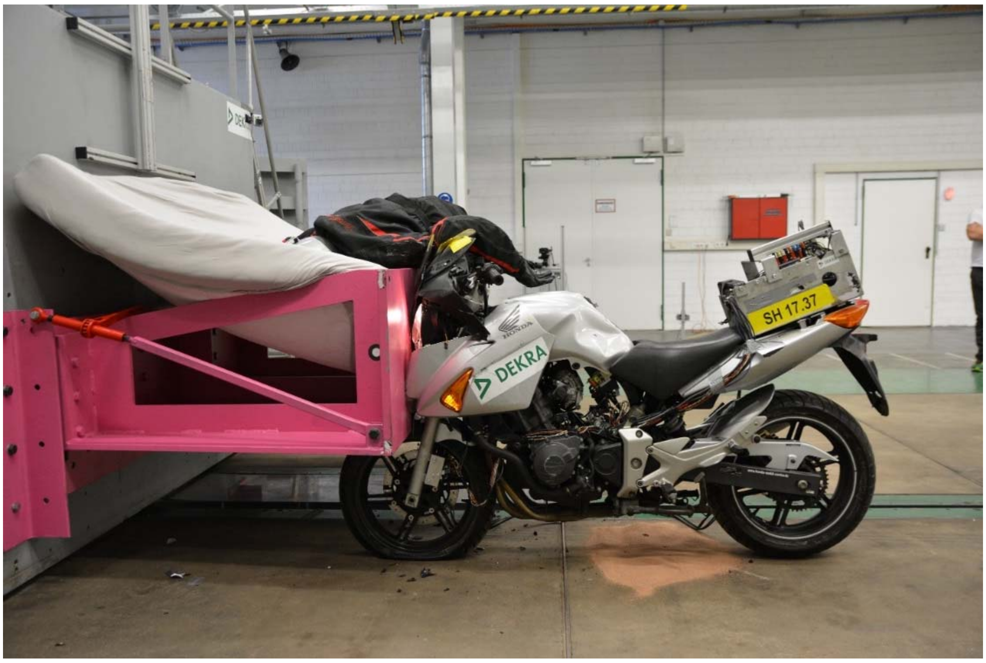

Figure 5: Crash test SH17_37, 40kph against trailer underride barrier

2.3. Studies and Tooling

2.3.1. Multibody Simulation Add-on in PC Crash (Tooling)

Therefore already in the beginning of the project one task was to analyse and assess the potentials of a multi body simulation tool for generating synthetic crash signals.

The so called BCT tool is a multibody simulation add-on in PC Crash developed by Fraunhofer IVI (Dresden). The used multi body system is composed of a rider model and a separate bike model. The rider model is the standard PC Crash pedestrian model repositioned into the seating position on the motorcycle. The model is composed of 20 bodies representing the main body parts e.g. torso, hip, thigh (2x), knee (2x). With 24 cm depth and 1.20 cm extent of the torso, 24 cm shoulder length and 80 cm of hip measurement the multi body model is comparable to a 50th percentile male Hybrid-III crash test dummy. Figure 18 shows the model in the final seating position. The rider model is fixed to the motorcycle by defined retention forces which reach their limits during a crash to realize the release of the rider due to acceleration.

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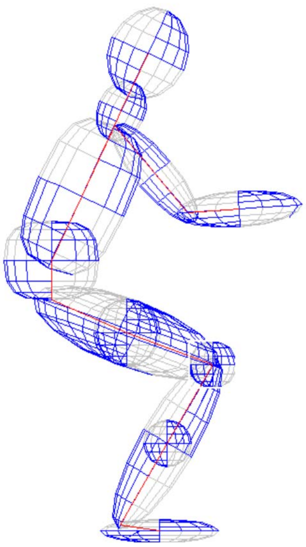

Figure 6: PC Crash multi body rider model

The motorcycle model is a modified multi body model based on the PC Crash model to represent an averaged motorcycle. The front fork, joint elements as well as spring elements are modified in this model for an optimized crash kinematic and signal feedback. It is composed of 11 bodies representing the main parts of a motorcycle, e.g. wheels, front and rear fork, engine block. It has a total length of 200 cm, a width of 80 cm and a total height of 105 cm. Figure 19 shows the modified motorcycle model.

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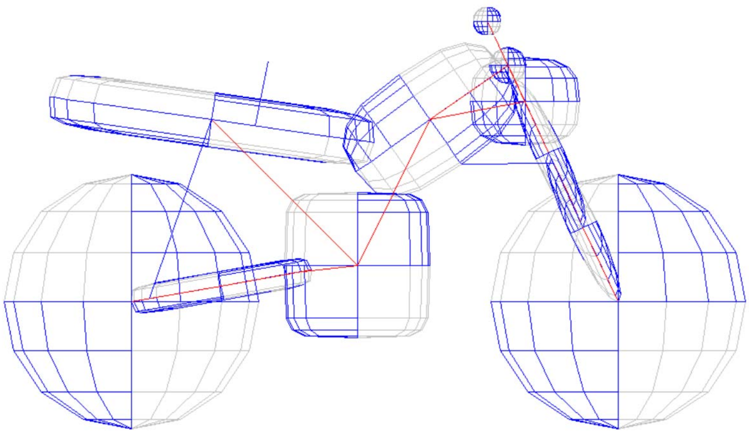

Figure 7: Modified multi body bike model

Several validation runs and reconstructions of real world crash tests showed a limited performance of the simulation tool. It underachieve the requirements of a tool for simulating a set of different accident cases and configurations using a generalized motorcycle model. Achieving realistic and reliable results were only possible by investing a high setup time of the model for only one crash configuration. This is in contrast to the limit signal quality which is possible to realize with the PC Crash multi body simulation tool.
In conclusion the output of the BCT tool in contrast to the setup time was not satisfying, therefore the further tool development as well as the usage of the BCT tool was stopped.

2.3.2. Injury Severity Estimation Study

The study on the injury severity estimation was conducted in a master's thesis that is accessible in FEBER on the reference "Motorcycle accident simulation and injury estimate" by Amir Abdel Nasser. The major results are summarized in the following including some examples of BCT usage.

The base point is the German In-Depth Accident Study (GIDAS) which provides the documentation of several motorcycle to vehicle accidents including the circumstances of the accident and occurred injuries of the rider. By focusing on vehicle to vehicle accidents the

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performed crash tests provide the loads and signals of the motorcycle and the dummy in case of an accident. As an outcome of this Figure 13 shows the technical methodology of combining crash signals with load on the human body on the way to a motorcycle based injury severity estimation.

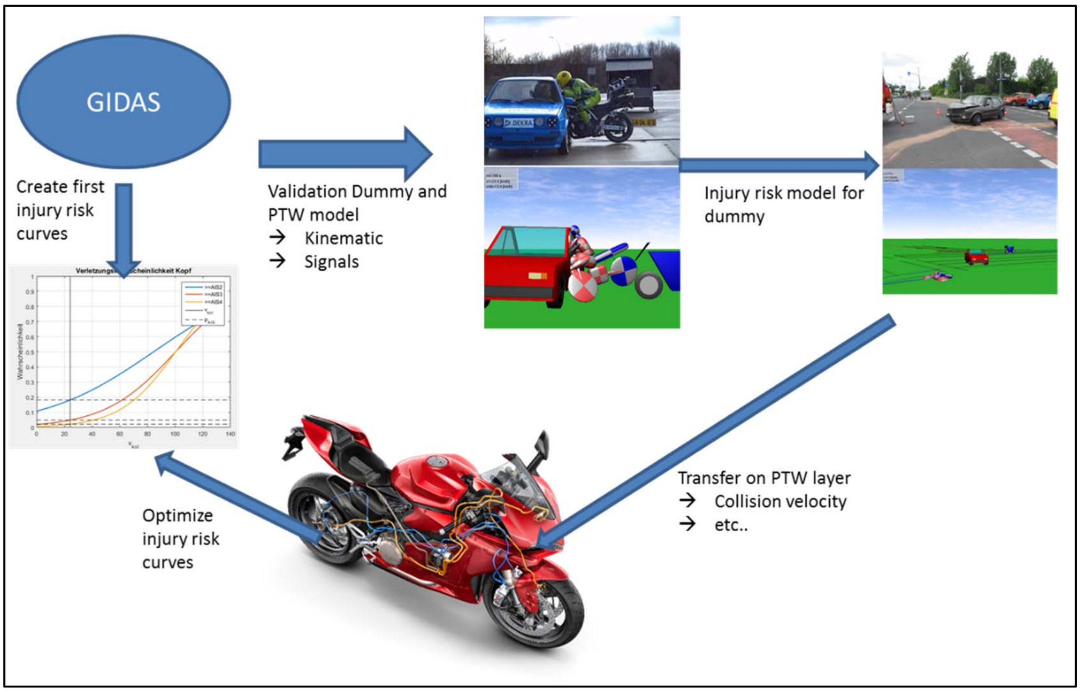

Figure 8: Overview of step by step transfer into simulation environment

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Development steps:

- The analysis of the GIDAS database delivers relevant information about the accidents like configuration, impact angle, speed, vehicle information and injury data for the reconstruction and first correlation between injury risk and real accident data.
- Validation of the multi body model in PC Crash based on the crash test signals of the dummy and the bike. Focus is on a good representation of the dummy load and the bike sensor signals in the center of gravity.
- Reconstruction of GIDAS accidents for analyzing the model performance in a realistic environment. Therefore the injury risk of the dummy is compared to the documented injuries in GIDAS.
- Transfer of the injury risk model into the motorcycle layer to find a correlation between sensor signals and injury risk.
- Optimization of the previous defined injury risk curves correlated to potential motorcycle sensor signals.

By using these development steps the definition of a corresponding injury risk curve will be described in the following.

Case Description

The reconstruction of specific motorcycle crash tests in the simulation environment enables the validation of the motorcycle and dummy model. This is necessary to correlate the multi body dummy load with the measured dummy load and the calculated injury risk during the real crash. Figure 7 shows an example for the reconstruction of a real crash test.

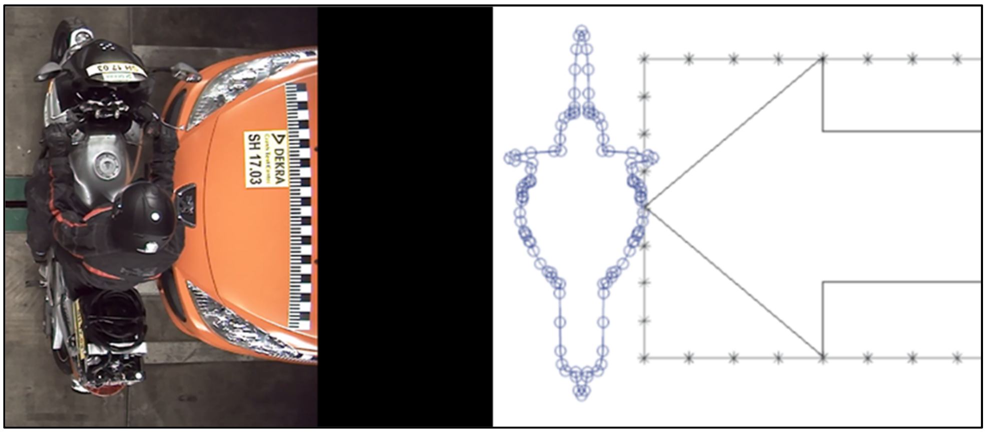

Figure 9: Reconstruction of motorcycle crash tests

To develop adequate models it is necessary to reduce the complexity of the real accident situation. Therefore the focus is on the first impact of the rider against the car, the assessment of the second impact, e.g. against the road, will not be considered in this study.

Example: ISO-Crash-Code 41X & 101X

The accidents of this crash configurations are characterized by a frontal impact of the motorcycle into the side of the opponent close to the B-pillar. This part of the vehicle is typically surrounded by stiff structural components, e.g. the roof edge, A- and C- pillar, what potentially decelerates the motorcycle and rider drastically. Figure 15 shows a crash test with ISO code 413 and the corresponding reconstruction in the BCT simulation environment.

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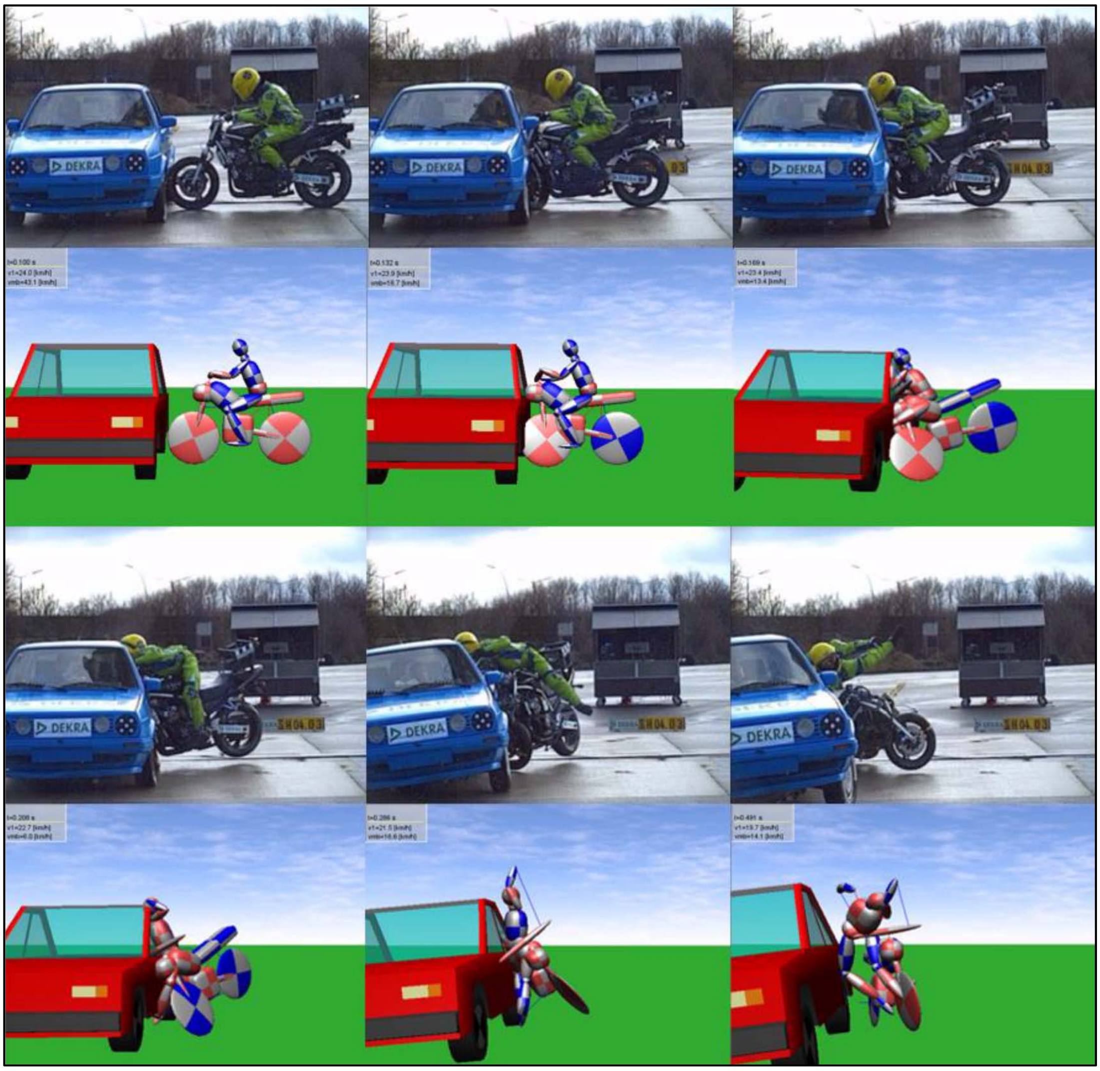


Figure 10: Crash SH0403 & reconstruction in simulation environment

Parameters to be studied

Various crash parameters can be identified as potential relevant to influence the rider's injuries severity. For the previous described crash configurations can be noted:

- collision angle α [°]
- collision speed v $[\frac{km}{h}]$

- motorcycle weight $m_{bike}[kg]$
- vehicle weight $m_{veh}[kg]$
- crash configuration

For the investigation on potential influence on the injury severity a parameter analysis is required. Varying the various parameters like the collision angle, crash configuration and collision speed causes a lot of simulation runs what has to be optimized by a Design of Experiment (DoE). Figure 9 shows an example for parameter analysis of different collision points and angles. The main focus for the injury analysis is on the head, neck and thorax assessed by the injury criteria HIC, Nij and Ac. The other extremities remain unconsidered.

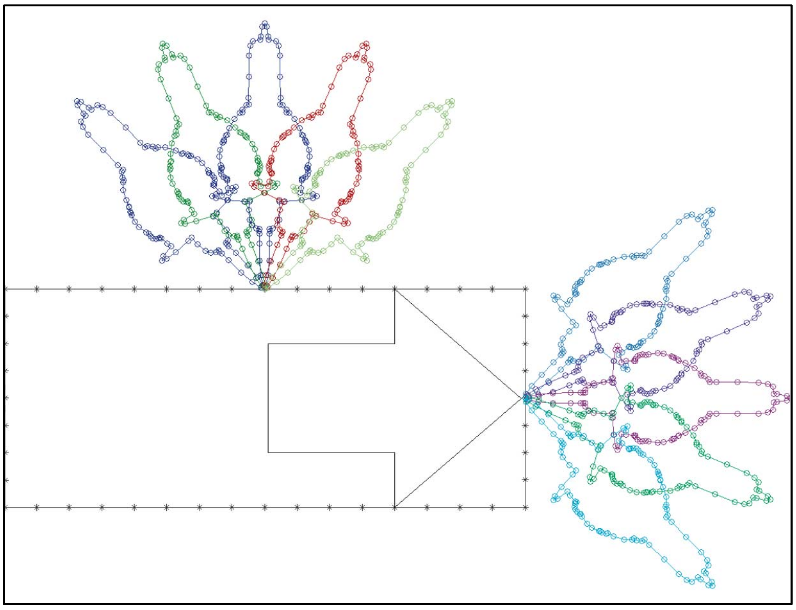


Figure 11: Parameter analysis in different crash configurations

Results: ISO-Crash-Code 41X & 101X

The analysis of bike to vehicle collisions showed a correlation between the collision angle α, – speed v and the load respectively the level of the injury criteria of the head, neck and thorax. However, the grade of correlation depends on the crash configuration itself. While the motorcycle itself hits stiffer or softer parts of the vehicle, the load on the rider depends on the point of its impact. As expected the grade of correlation is higher at accidents in which the rider hits the vehicle directly on stiff parts (e.g. roof edge) comparable to the impact of the bike, than at accidents in which the rider got thrown over or on the vehicle (e.g. hood).

Based on the findings on relevant collision parameters the potential injury risk or respectively risk for injury severity can be calculated by using predefined 2D injury risk curves, e.g. a HIC over AIS correlation. The calculated multidimensional injury risk for AIS2 for the head is represented as an example for a realized estimator for ISO Crash Code 41X and 101X in Figure 10.

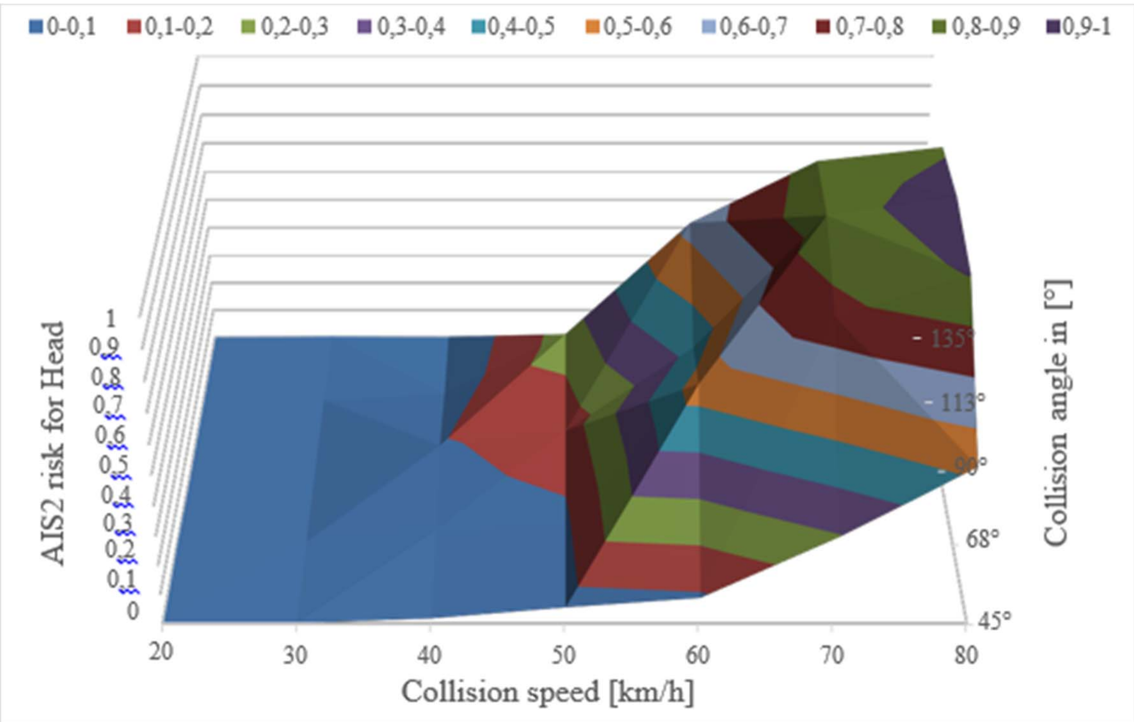


Figure 12: AIS2 risk for the head in ISO-Crash-Code 41X & 101X

This kind of visual representation is possible for all body regions and for each AIS level. The integration of additional injury criteria or AIS level into the diagram isn't convenient for a better understanding. To estimate the overall load of the rider or of each body region a separate injury estimation model for the corresponding body has to be defined.

The final assessment of an onboard injury severity estimation in the ABS/eCall system showed that the realization of such a prototypical solution is in the current status not robust enough. For bike to vehicle accidents the vehicle defines the shape of the collision opponent for the rider therefore the collision angle and impact point could be identified as relevant parameter for an adequate estimation of an injury severity of the rider. The approach of this estimation is based on the 3D acceleration sensor signals of the motorcycle in front crash and side impact scenarios. That causes limitations for the range of the estimation because it just records the impact of the bike against an opponent. Further there is a lag of information about the impact point of the rider at the first impact and no information about the potential second impact of the rider against other objects. Therefor additional sensors on the rider are required, e.g. sensor information from airbag jackets and need to be analyzed in a further study.

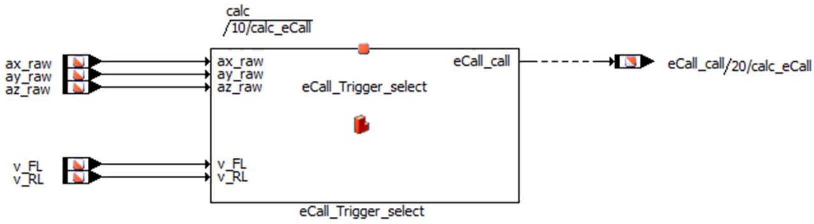
The injury severity estimation was not further developed or implemented in the eCall system of this project.

2.4. Improved Algorithm & ASCET implementation

The so far developed basic algorithm had a structure of three situation estimator (Normal Ride, Crash and Final Position). The results of each estimator were combined and finally assessed in the subsequent state machine. The output was a signal whether an eCall should be launched or not.

This original structure has been retained and partly extended. The following includes a short technical description of the ASCET implementation in combination with the improvements. The ASCET classes are currently adapted for an inclusion into the MSC software running in an ABS ECU using properties of the MM5.10 sensor. It uses some classes already available in the MSC software (*MSC_RootCore* and *MSC_SquareRoot* and related parameter classes) for elementary arithmetic operations. The algorithm is designed and tested to run in the 10ms task.

2.4.1. ASCET Class eCall_Trigger_select



The class eCall is the main class including the complete eCall algorithm.

Inputs:

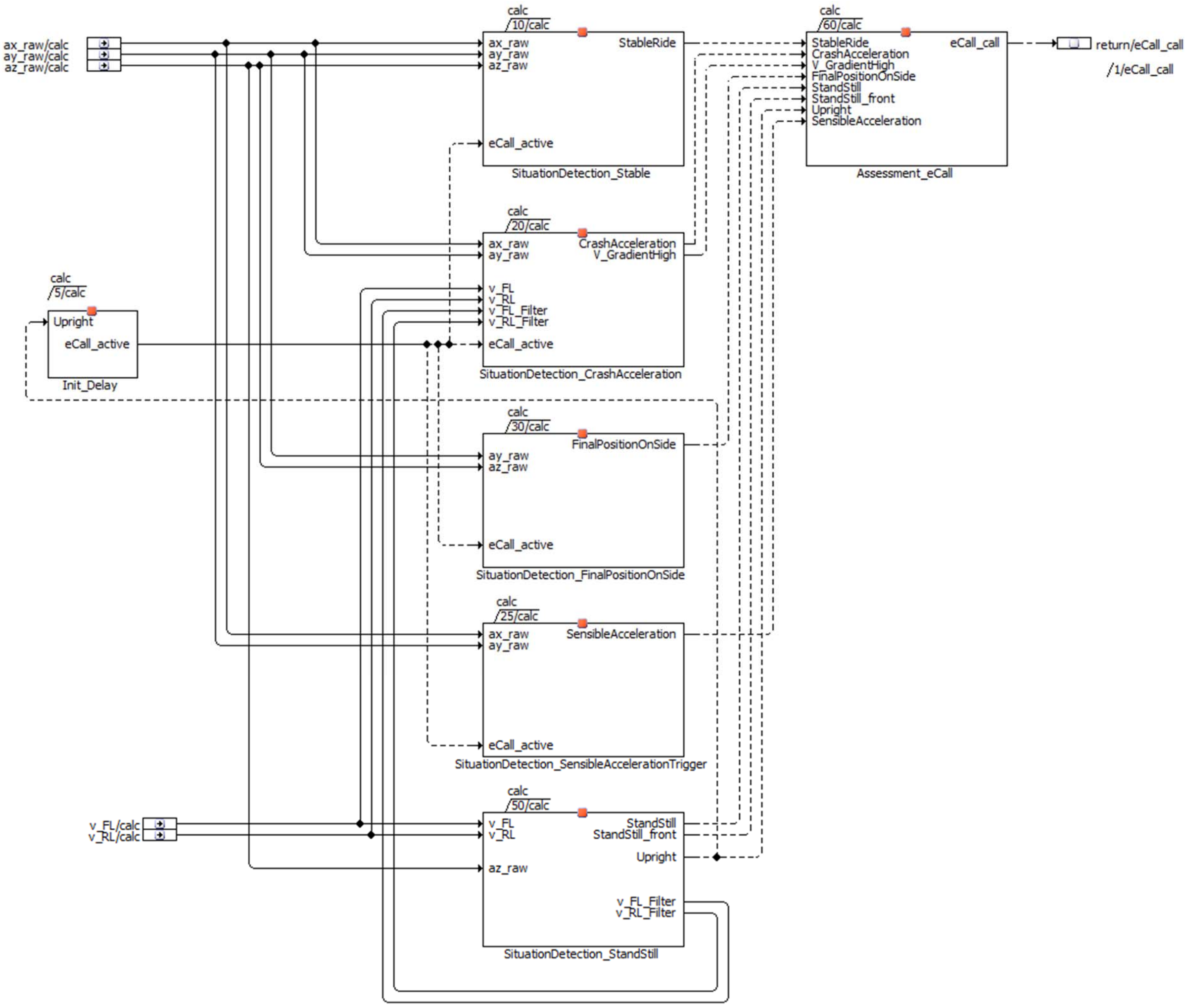
- *v_FL, v_RL*: front/rear wheel speeds as used also by MSC algorithm
- *ax_raw, ay_raw, az_raw*: Ax,Ay,Az-accelerations in vehicle coordinates as calculated by the MSC algorithm

Outputs:

- eCall_call: eCall trigger flag.
  0 = no eCall
  1 = eCall trigger

Depending on the complete software/data bus architecture the trigger flag have to be passed further e.g. into a CAN bus signal.

Substructure of class eCall:



The subclasses are described in the following chapters.

2.4.2. ASCET Class SituationDetection_Stable

At normal riding one expects always some excitation of the acceleration sensors of the IMU. The core idea of this class is to detect stable riding by observing the accelerations. This indication doesn't trigger an eCall directly but will be further used in the state machine as described in chapter 2.4.8. As indication of normal riding the length of the complete acceleration vector is used. After PT1-filtering it is observed if the acceleration vector length is below its value of the previous time step multiplied by a factor of 1.02 (*eCall_AresStableRange*). If the acceleration vector length is continuously within this 2% range around its previous value a time counter increases. If the time counter reaches a given threshold (*eCall_StableTimeMax*) a flag is set which indicates that the bike is now in a suspiciously steady state. This criterion is used in the class *Assessment_eCall* (as described in chapter 2.4.8) in combination with other suspicious states to decide if eCall triggering is necessary or has to be suppressed.

2.4.3. ASCET Class SituationDetection_CrashAcceleration

This class includes an evaluation of acceleration clipping lengths and also an evaluation of the velocity gradient. From a programming logical point of view these two criteria are independent. Both criteria are relevant mainly for object collision accidents. The velocity gradient criterion also recognizes the special case if the bike crashes into a very rigid obstacle and get stuck upright without reaching the clipping times of the acceleration clipping criterion (due to very short but high peaks, which are cut by the measurement range limits of the acceleration sensor).

For the velocity gradient observation an additional time counter is used creating an evaluation time frame equal to the minimum of the parameters *Ax_Clip_Time_Lim* and *Ay_Clip_Time_Lim*. At first a high Ax threshold has to be reached (-1 * *eCall_a_Clip_Lim*). If this is the case in the next time step the gradient of the velocity is evaluated. If the (negative) gradient is below a given threshold (*eCall_v_FL_gradient_min*) a suspicious flag is set. If in the next ASCET task time step the current front wheel speed is lower than a given threshold (*eCall_v_grad_min*) which means that the ride doesn't continue with stable speed the velocity criterion will trigger an eCall in the class *Assessment_eCall* immediately. An illustrative example with further details is described in chapter 2.4.10.

The second trigger criterion in this class evaluates the time span of clipping of Ax and Ay. With the acceleration sensor range of the MM5.10 sensor typical clipping lengths of 30ms – 50ms appear at collision accidents.

First the threshold of clipping length is determined by evaluating the maximum velocity of the front and rear wheel in comparison. The used velocity signal is PT1-filtered (output of class *SituationDetection_Standstill*) and is further delayed by an amount of the minimum of *Ax_Clip_Time_Lim* and *Ay_Clip_Time_Lim* to ensure that a velocity is considered which the bike had short before the impact into an obstacle. In general typical clipping lengths are shorter at low velocities. Nevertheless one exception is considered: it has been observed that at the special case of maybe uncritical crashes against walls with very slow velocities show longer clipping lengths then critical vehicle collisions at moderate velocities. For this purpose in the velocity interval *eCall_v_min* to *eCall_v_a_clip_time_slow* (currently recommended 1.39 m/s to 2.777 m/s, equal to 5 km/h – 10 km/h) the clipping length for the Ax signal with negative values is slightly increased (*eCall_ax_Clip_Time_VeryLowSpeed*). If this special case should also trigger an eCall in this case the parameter can be set equal to the parameter *eCall_ax_Clip_Time_LowSpeed*.

2.4.4. ASCET Class SituationDetection_FinalPositionOnSide

At normal riding the values of Ay are nearly zero and the Az values in average show the gravity acceleration g. This class evaluates if the bike has been capsized or has reached an upside down final position. For this purpose first Ay and Az are PT1-filtered. If the Ay value is between the defined interval between *eCall_AySideMin* and *eCall_AySideMax* (currently from 7 m/s² to 11 m/s²) a time counter increases. If the time counter reaches a defined threshold (*eCall_AyTimeMax*) the flag *FinalPositionOnSide* is set which is further evaluated in the class *Assessment_eCall*.

Analogously if the Az value is between the defined interval between *eCall_AzSideMin* and *eCall_AzSideMax* (currently from -11.5 m/s² to 3.5 m/s²) a time counter increases. If the time counter reaches a defined threshold (*eCall_AyTimeMax*) the flag *FinalPositionOnSide* is set which is further evaluated in the class *Assessment_eCall*.

2.4.5. ASCET Class SituationDetection_SensibleAccelerationTrigger

This criterion is used to detect a collision only in situations near or at standstill. It just compares the current Ax and Ay values with determined thresholds (*eCall_AxSensibleMin* and *eCall_AySensibleMin*). If one of these thresholds is exceeded the flag *TriggerSensible* is set which leads to eCall triggering at stand still by the class *Assessment_eCall* immediately.

Also included in this class is a simple testing procedure for eCall triggering in stand still without crashing the bike: if the logical parameter *FS_eCall_Test_Trigger* is changed to "true" than an eCall is triggered if Ay reaches the threshold defined by FS_eCall_Test_Trigger_Ay_Threshold. The value of this parameter is currently 3.5m/s² which equals a lean angle of ~20° on flat ground. So the complete trigger chain can be tested by simply slightly leaning the bike.

2.4.6. ASCET Class SituationDetection_Standstill

This class evaluates if the bike is in or near a standstill state and upright.

First the wheel velocities are PT1-filtered. Both wheels are evaluated separately. If the wheel velocity gets below a defined threshold (*eCall_v_min*) a time counter is increased. If the time counter reaches a defined maximum (*eCall_Standstill_Time_min*) the belonging StandStill_front/rear-flag is set.

For the detection of the upright condition Az is used which is normally ~+9.81 m/s² in standstill. If Az is larger than a defined threshold (*eCall_AzUprightMin*, currently 8.89 m/s² which corresponds to a lean angle of 25° on flat ground), then a time counter increases till exceeding a defined threshold (*eCall_Upright_Time_min*). If this is the case a temporary upright flag is set. In the next step the state of this flag is delayed using again a time counter. This prevents changing the upright state at side crash accidents before Ay reaches values to trigger by acceleration limits of the class described in 2.4.5.

2.4.7. ASCET Class Init_Delay

This class delays all relevant flags for eCall triggering to prevent false triggering possibly caused by delayed initialization of sensors. After restart of the system first it is checked if the bike is in upright position (output of class *SituationDetection_Standstill*, chapter 2.4.6). The upright position check is necessary to prevent eCall triggering if the ignition is turned on if the bike is already capsized. If the upright condition is fulfilled a time counter increases until a defined time span has been exceeded (*eCall_Init_Time*) added by the time delay of the upright condition (*eCall_TimeUpright_delayed_max*) because the upright condition flag has a delay by its own. After exceeding this time span all flags in the sub classes relevant for eCall triggering are able to be set.

2.4.8. ASCET Class Assessment_eCall

This class finally triggers an eCall after evaluating the riding state attributes offered by the classes described above. From a software technical point of few this class offers a state machine which represents several riding states (it is not implemented as an ASCET built-in state machine).

The states are enumerated and represent the following states:

- state 0: normal riding
- state 1: waiting state after suspicion of capsized bike
- state 2: eCall triggering
- state 3: stand still condition

State 0 is the normal riding state. If capsize seems to have happened (see 2.4.4) it switches to state 1 to wait if the riding continues in a stable way. If clipping limits of the acceleration signals are reached (see 2.4.3) it switches immediately to state 2 for eCall triggering. If a standstill and upright state is detected (see 2.4.6) it switches to state 3.

In **state 1** a time counter is increased. After reaching a defined time limit (*eCall_LimitTimeInWait*) it is checked if the riding continues in a stable way (see 2.4.2). If this is the case it switches back to state 0. If the time limit is reached and the bike doesn't ride stable or if in the meantime an acceleration signal clipping limit is reached (object collision) it switches to state 2 for eCall triggering.

State 2 finally triggers an eCall and remains in its state till the system is restarted.

State 3 is reached if an upright and stand still condition is detected. It remains in this state until the front wheel is moving again or an acceleration limit of the criteria in chapter 2.4.5 is reached.

If the front wheel moves again first it is checked if the bike is still not in a capsized state detected by the criteria described in ch. 2.4.4 before switching to state 0. Otherwise the capsized state would be detected like after previously normal riding condition which leads to eCall triggering. Therefore even if the front wheel moves after capsize in standstill due to certain reasons a standstill capsize will not be detected (which is currently the desired behavior).

Observing the rear wheel is not advisable in this case because at some bikes a capsize leads to changing the gear from neutral to some other states due to touching the ground of the gear switch and also declutching while fall-down will lead to a moving rear wheel however the bike is still in standstill condition where no eCall should be triggered after capsize.

2.4.9. ASCET Parameter Class eCall_Parameter

Parameter	Value	Unit	Meaning	Application hints
eCall_a_Clip_Lim	40.97	m/s	Limit of clipping of acceleration-sensors; subtract tolerance of 0.001953125 due to implementation	Adapted to MM5.10 standard configuration, may also be kept for sensors with higher measurement range, then also clipping lengths below have to be kept.
eCall_AresStableRange	1.02	-	Factor for absolute acceleration band for stable range	
eCall_ax_Clip_Time_HighSpeed	0.05	s	Ax clipping time limit at high velocity	Relevant above the velocity *eCall_v_a_clip_time_high*
eCall_ax_Clip_Time_LowSpeed	0.03	s	Ax clipping time limit at low velocity	Relevant between the velocities *eCall_v_a_clip_time_slow* and *eCall_v_a_clip_time_high*
eCall_ax_Clip_Time_VeryLowSpeed	0.04	s	Ax clipping time limit near walking speed	Relevant between the velocities *eCall_v_min* and *eCall_v_a_clip_time_slow* .

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				If gentle crashes against walls should also trigger an eCall set value equal to *eCall_ax_Clip_Time_LowSpeed*
eCall_AxSensibleMin	30.0	m/s²	Ax threshold for sensible trigger	Relevant at stand still. Should be high enough to avoid eCall triggering by roughly touching walls while ranking.
eCall_ay_Clip_Time_HighSpeed	0.05	s	Ay clipping time limit at high velocity	Relevant above the velocity *eCall_v_a_clip_time_high*
eCall_ay_Clip_Time_LowSpeed	0.025	s	Ay clipping time limit at low velocity	Relevant between the velocities *eCall_v_a_clip_time_slow* and *eCall_v_a_clip_time_high*
eCall_AySensibleMin	30.0	m/s²	Ay threshold for sensible trigger	Relevant at stand still. Should be high enough to avoid eCall triggering by roughly touching walls while ranking.
eCall_AySideMax	11.5	m/s²	Upper Ay threshold for position on side criterion	
eCall_AySideMin	7.0	m/s²	Lower Ay threshold for position on side criterion	
eCall_AyTimeMax	1.0	s	Maximum time at suspicious Ay values	
eCall_AzSideMax	3.5	m/s²	Upper Az threshold for upside down position criterion	
eCall_AzSideMin	-11.5	m/s²	Lower Az threshold for upside down position criterion	
eCall_AzTimeMax	1.0	s	Maximum time at suspicious Az values	
eCall_AzUprightMin	8.89	m/s²	Az for upright condition (Az = g * cos (lean angle in upright state))	Hint: up to road slopes of ~30% pitch correction not obligatory necessary (see 2.6)
eCall_FinalAyFilterK	10.0		Filter parameter divided by GlobalTimeStep for Ay at final position criterion	

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eCall_FinalAzFilterK	10.0		Filter parameter divided by GlobalTimeStep for Ay at final position criterion	
eCall_g	9.81	m/s²	Gravity acceleration	
eCall_Init_Time	0.5	s	Init time delay while eCall is not active	May be set to values for initialization of communication hardware.
eCall_LimitTimeInWait	0.1	s	Time limit for waiting at suspicious state	
eCall_Signal_Time_Limiter	false	-	Optional: to limit the time span of eCall=true - signal	For optional reset of eCall-trigger state after defined time span without restarting the ECU.
eCall_Signal_Time_Max	2.0	s	Time span of eCall-Signal = true, only relevant if eCall_Signal_Time_Limiter = true	
eCall_StableAyFilterK	4.0		Filter parameter divided by GlobalTimeStep for Ay at stable criterion	
eCall_StableTimeMax	0.3	s	Time limit for stable ride criterion	
eCall_Standstill_Time_min	1.0	s	Time span for still stand criterion	If ABS is active this parameter may be reduced down to typical ABS blocking times of wheels.
eCall_TimeUpright_delayed_max	0.05	s	Time delay for upright flag	
eCall_Upright_Time_min	0.1	s	Time span for upright state evaluation	
eCall_v_a_clip_time_high	5.555	m/s	Velocity limit for switching acceleration clipping time from low to high	
eCall_v_a_clip_time_slow	2.777	m/s	Velocity limit for choosing acceleration clipping time for slow velocities	
eCall_v_FL_gradient_min	-60.0	m/s²	Threshold of velocity gradient criterion	
eCall_v_grad_min	2.0	m/s	Velocity threshold for wheel speed gradient criterion	
eCall_v_min	1.39	m/s	Minimum velocity for stand still criterion	

eCall_vFilterK	15.0		Filter parameter divided by GlobalTimeStep for velocity filtering	
FS_eCall_Test_Trigger	false		For trigger test only (see next parameter)	
FS_eCall_Test_Trigger_Ay_Threshold	3.5	m/s²	For trigger test only; Trigger at this Ay value (at controllable lean angles) while stand still	value equals ~ | 9.81m/s² * sin(lean angle) |

2.4.10. Exemplary accidents evaluated by the ASCET implementation

Lowsider

This is a typical example of a single accident which is recognized by the final position of the bike lying on side. This criterion will always trigger an eCall if the accident happens above a given velocity threshold (see stand still criterion, ch. 2.4.6). Especially in the example in the figure below it is interesting that the wheels came to a stop before the bike reaches the final rest position. To assure that the algorithm doesn’t switch into the stand still state in the state machine the StableRide flag (see ch. 2.4.2) is also considered which will be in true-state until the bike is in rest position.

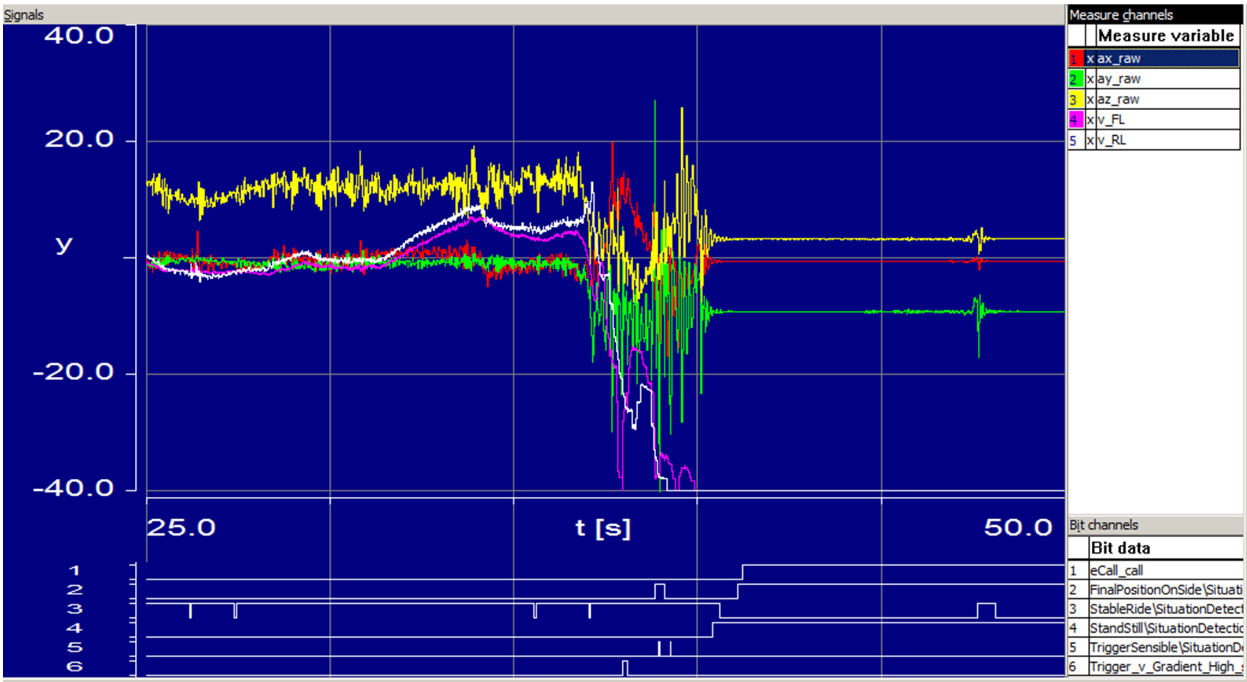

Figure 13: MM5.10 & ABS signals of a lowsider
(the y-scale belongs to the acceleration signals)

Wall collision

The figure below shows an example of side-wards sliding along a massive obstacle (curved concrete wall). This accident type is easily detected by the clipping length of Ay (see 2.4.3).

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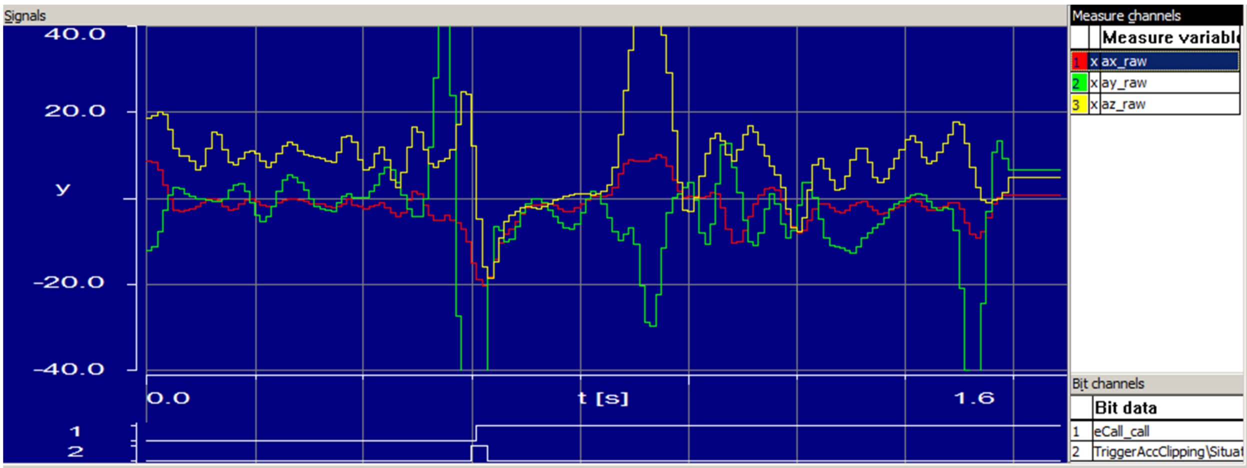

Figure 14: MM5.10 signals of a wall collision (side-wards)
(the y-scale belongs to the acceleration signals)

Fall down while stand still

The figure below shows the acceleration progressions while fall down in stand still mode. Obviously the FinalPositionOnSide-flag is set but the state machine doesn't allow eCall triggering due to evaluating the standstill condition additionally.

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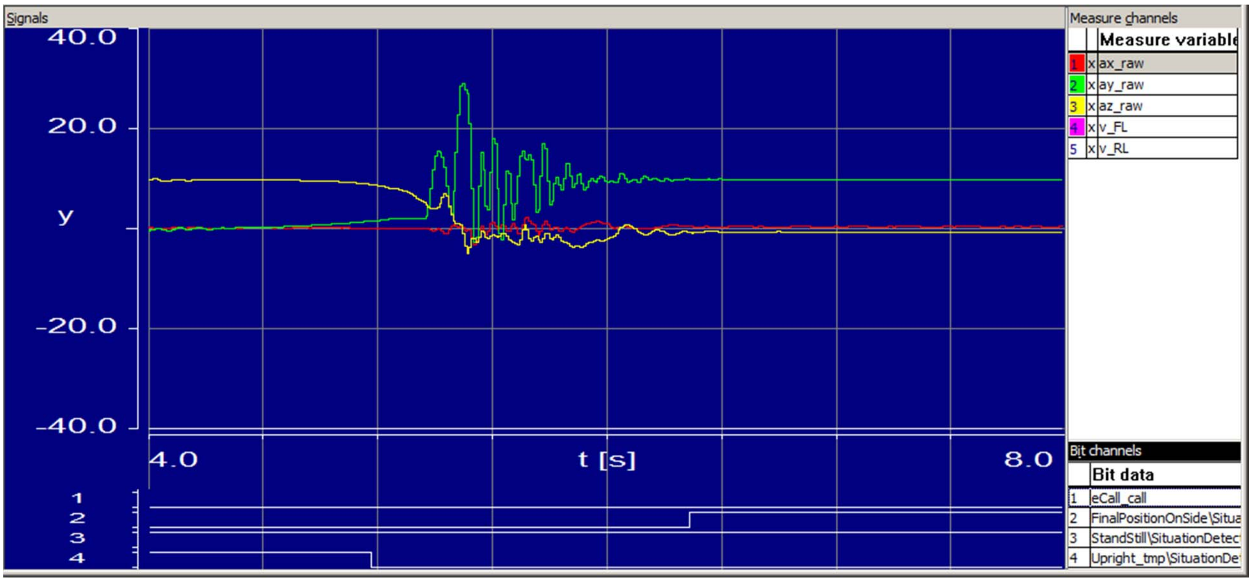

Figure 15: MM5.10 signals of fall down at standstill
(the y-scale belongs to the acceleration signals).

Passenger car side crash while stand still

In standstill mode of the state machine the only way to trigger an eCall is a collision that excites the acceleration sensors to the limits described in ch. 2.4.5. The figure below shows an example of this accident type. Obviously the clipping criterion is not set (*TriggerAccClipping*) but the threshold of the sensible trigger criterion triggers an eCall immediately.

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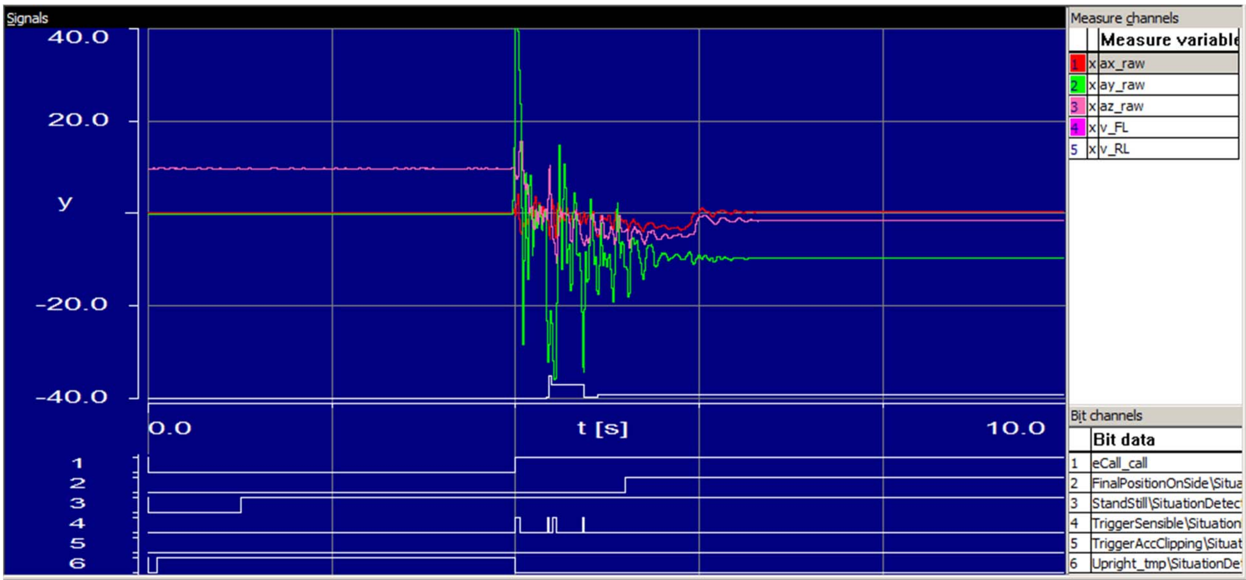

Figure 16: MM5.10 & ABS signals of a side impact of a passenger car
(the y-scale belongs to the acceleration signals)

Crash into underride guard with bike getting stuck upright

In this crash test the motorcycle crashed into the mockup of an underride guard of a truck and get stuck in upright position. Issue in this case is that a very high but also short Ax peak appears. Around 4.7s in the figure Ax (turquoise curve) is cut at ~ -40m/s² by the limits of the MM5.10 sensor but due to the very high crash dynamics no considerable clipping time appears. The velocity raw signal of the front wheel (yellow curve) show some dynamics and disturbances while touching the obstacle. The algorithm evaluates the PT1-filtered velocity signal (magenta curve) and the gradient of it with an additional time shift and longer evaluation steps. This assures that the main negative gradient appears after the main peak of Ax which is the first criterion to detect this accident type in a timing sense. Another possibility for the implementation would be to detect a high negative velocity gradient and then to observe if a high negative Ax peak appears afterwards. In this case it has to be assured that the time delay due to velocity filtering isn't too large.

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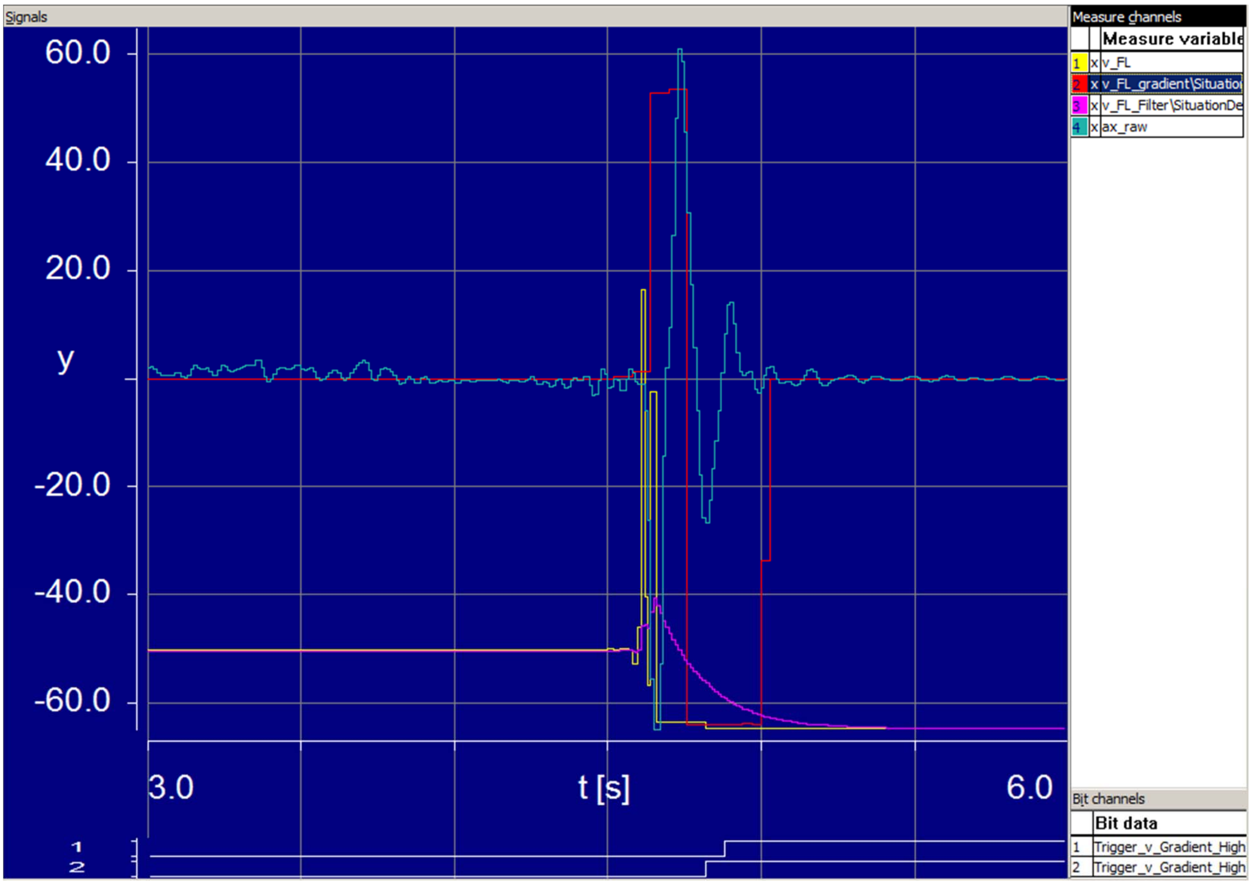

Figure 17: MM5.10 & ABS signals of the impact into an underride guard
(the y-scale belongs to the velocity gradient signal)

2.4.11. Performance test on the database

The performance of the improved algorithm was tested in an offline test against the full database of 812 files (200h). Therefore the algorithm was implemented via PSL block exported by ASCET into the Matlab Simulink development environment (see Figure 18). That enables the offline simulation with the complete database as input.

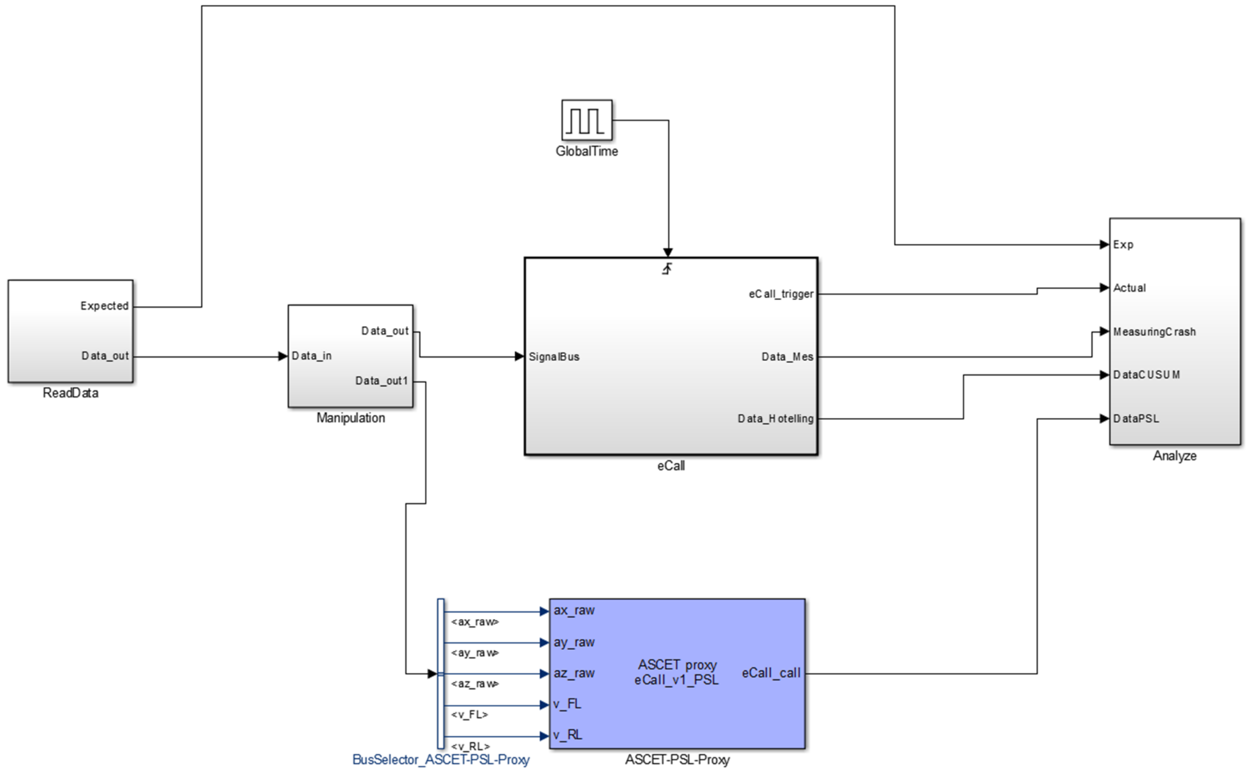

Figure 18: ASCET PSL integration into Matlab Simulink

The performance test showed a good result for the improvements for the advanced algorithm. Table 1 shows the comparison of the basic and advanced algorithm.

Type:	Number of Cases	Right classified: Basic Algorithm	Right classified: Advanced Algorithm
Misuse Case	744	733	741
Use Case	68	59	67
Total:	812	792	808

Table 1: Results of performance test

The use case in the advanced algorithm performance which is not covered is a low sider event. It arise from a missing final position in the data of the low sider because of the data set ends before the bike is in a final position.

One of the false detected events of the misuse cases is a simple override of a squared timber block at 30kph which show high acceleration peaks in the Ax direction. Hence the SituationDetection_CrashAcceleration block triggers an accident. During the prototype tests these signals out of the MDS database were not repeatable whether with the KTM 1290 Super Adventure R nor with the Aprilia Tuono RSV 4 sports bike. Further there is a big gap between the signals out of the MDS database and the prototype tests for this event. That leads to the conclusion that the signals of the MDS database for this event are potentially not reliable.

The other two remaining misuse cases which are false detected as an accident are events of hitting a rigid wall in the low speed rang 8-9kph currently classified as non-trigger events. The hitting wall events at low speed are corner cases. Therefore the SituationDetection_CrashAcceleration block (see 2.4.3) provides a function to include or exclude this type of events to the non-trigger events during the application of the algorithm parameter.

2.5. P2W eCall prototype

In order to demonstrate the functionality of a complete motorcycle eCall system two demonstrators were built up. For testing the system adaptability, the chosen bikes were of different type, a travel bike (KTM 1290Super Adventure R) and a sports bike (Aprilia Tuono 1100). The riding tests included some types of accidents where an eCall should be triggered and also non-trigger maneuvers with high excitation of the bike. In the following all technical components and test scenarios are described in more detail.

2.5.1. eCall prototype system overview

The architecture for the prototypical eCall system is sketched in Figure 19. An inertial sensor unit measures the accelerations in three dimensions, wheel speed sensors detect the velocities of the front and rear wheel. These data are sent to the ABS-ECU by CAN signals. The ABS-ECU software also includes the accident detection algorithm. If the algorithm detects an accident a CAN-trigger-signal is sent to the CCU which is also connected with the vehicle CAN. On the handle bar a HMI-device is mounted with status LEDs and an eCall suppression button. The

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audio interface activates an acoustic signal (buzzer). These components were installed on two test bikes as described below, all components are further described in the following chapters.

It must be pointed out that this setup is only an example of a complete eCall system. Other configurations with a more compact design could also have been built-up, i.e. integration of the accident detection algorithm into the CCU.

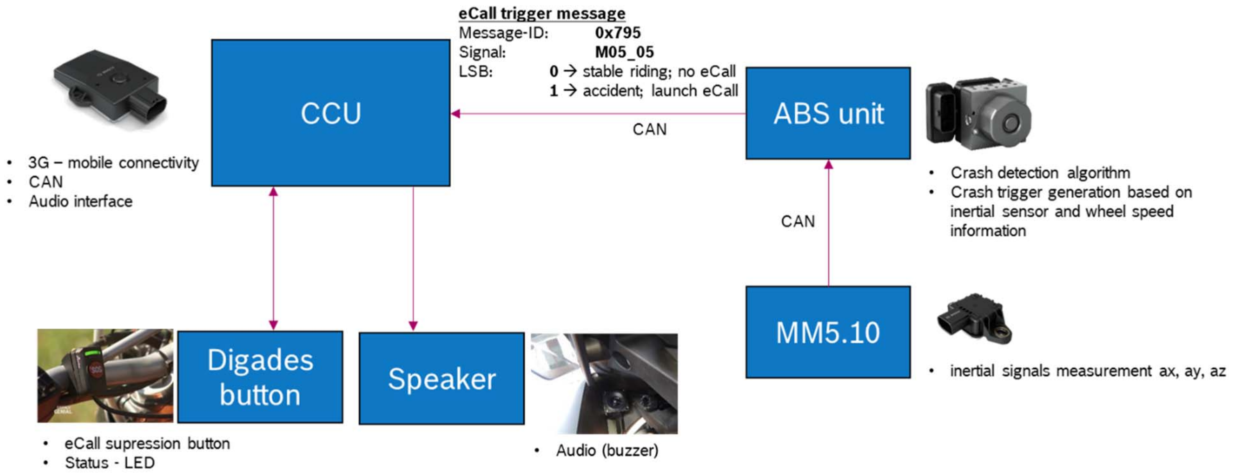

Figure 19: eCall prototype system overview

2.5.2. Test bikes

Piaggio provided the sport bike Aprilia Tuono 1100 (model year 2015) as shown in Figure 20. Some technical data can be found in Table 2. The bike was already equipped with an inertial sensor box but for the current ABS software including the accident detection algorithm it was necessary to exchange the ABS unit with the current ABS 9MP aggregate for which ASCET 6 software is available.

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Figure 20: Aprilia Tuono 1100

CAPACITY	1077 cc		**FUEL**	Unleaded petrol
POWER	175 cv at 11000 rpm		**FRONT TYRE**	120/70 ZR 17"
WEIGHT	184 kg		**REAR TYRE**	200/55 ZR 17"
HEIGHT	825 mm			
LENGTH	2.070 mm			

Table 2: Main technical characteristics of the Aprilia Tuono 1100

As a bike from the travel/enduro segment KTM provided the current Super Adventure 1290 R. This bike is already equipped with the latest BOSCH ABS aggregate and a BOSCH inertial sensor unit. The bike is shown in Figure 22, some technical data can be found in fig. 63.

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Figure 21: KTM Super Adventure 1290 R

CAPACITY	1301 cc	**FUEL**	Unleaded petrol
POWER	118kw	**FRONT TYRE**	90/90 ZR 21"
WEIGHT	217 kg	**REAR TYRE**	150/70 ZR 18"
HEIGHT	890 mm		
WHEEL STAND	1580 mm		

Table 3: Main technical characteristics of the KTM Super Adventure 1290 R

2.5.3. Inertial sensor box

In both bikes the BOSCH inertial sensor box MM5.10 was used. It offers acceleration data in three dimensions and turn rate data in two dimensions. Within the current accident detection algorithm only the acceleration data was used. In the Aprilia Tuono the sensor is mounted below the seat bench, in the KTM Super Adventure the sensor is mounted between tank and engine.

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2.5.4. ABS-ECU including accident detection algorithm

Before the bike integration the accident detection algorithm was tested with simulative methods and the usage of an extensive maneuver catalogue including about 700 sets with sensor data of riding situations. The data base contains several accident types (collisions, low/high sider, capsizes) as well as accident-free rides with high excitation (off-road, bad roads, caught near accidents).

The accident detection algorithm was directly integrated into the software components of the vehicle state estimation as used for the lean angle dependent ABS functionality. The KTM Super Adventure 1290 already used the current ECU and software, only the accident detection algorithm was added to the original software. The Aprilia Tuono (model year 2015) was updated with a new ABS aggregate and current ECU software for lean angle dependent ABS functionality where the accident detection algorithm could be integrated in the same way as in the KTM bike. In both ECUs the standard ABS-CAN interface was modified offering an additional message for sending a trigger signal in case of a detected accident.

In both bikes the ABS unit is mounted in a central and well protected position between seat bench and engine, so in most cases no immediate damage in case of an accident is expected.

2.5.5. Central Communication Unit (CCU)

The CCU as the central communication device is shown in Figure 24. It is connected to the vehicle CAN for receiving the accident detection trigger signal from the ABS-ECU in the current setup. It also is connected to the HMI as described in the next chapter and to a buzzer for acoustic indication of a detected accident.

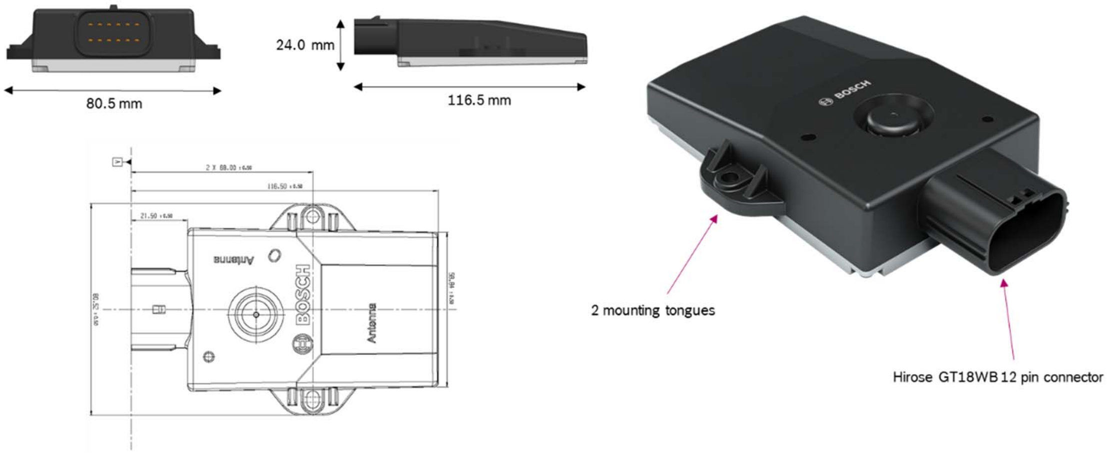

Figure 22: Housing of CCU

For the optimum functionality of the CCU regarding crash safety and connectivity there are some recommends for finding a convenient mounting position. The CCU should be covered under a plastic shield near the outer shell of the motorbike and not behind any part of the rider.

At the test bikes the CCU was prototypically integrated into the pillion rider seat (Aprilia Tuono; the tests as described below were done without pillion rider) respectively in the rear area under the complete seat bench (KTM Super Adventure).

Future studies are required for determining the most suitable position, regarding also the most robust CAN-connection so that CAN communication is ensured also in case of a severe collision.

2.5.6. HMI interface

On both bikes a handle bar module from Digades were mounted (see. Figure 25) and connected with the CCU. Beside the Buzzer connected with the CCU an eCall pre-trigger is now visible by LEDs and the eCall can be suppressed by pushing a button between a defined time span (20s recommended) in case of an unharmed or slightly injured rider.

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Figure 23: HMI with LED and eCall suppress button

2.5.7. MSD setting for eCall demonstration

According to document EN 15722 [6] the MSD setting function is implemented in the CCU device. For simplifying the activity of testing and development of eCall function an on HostPC tool by CEIT was prepared (see figure below).

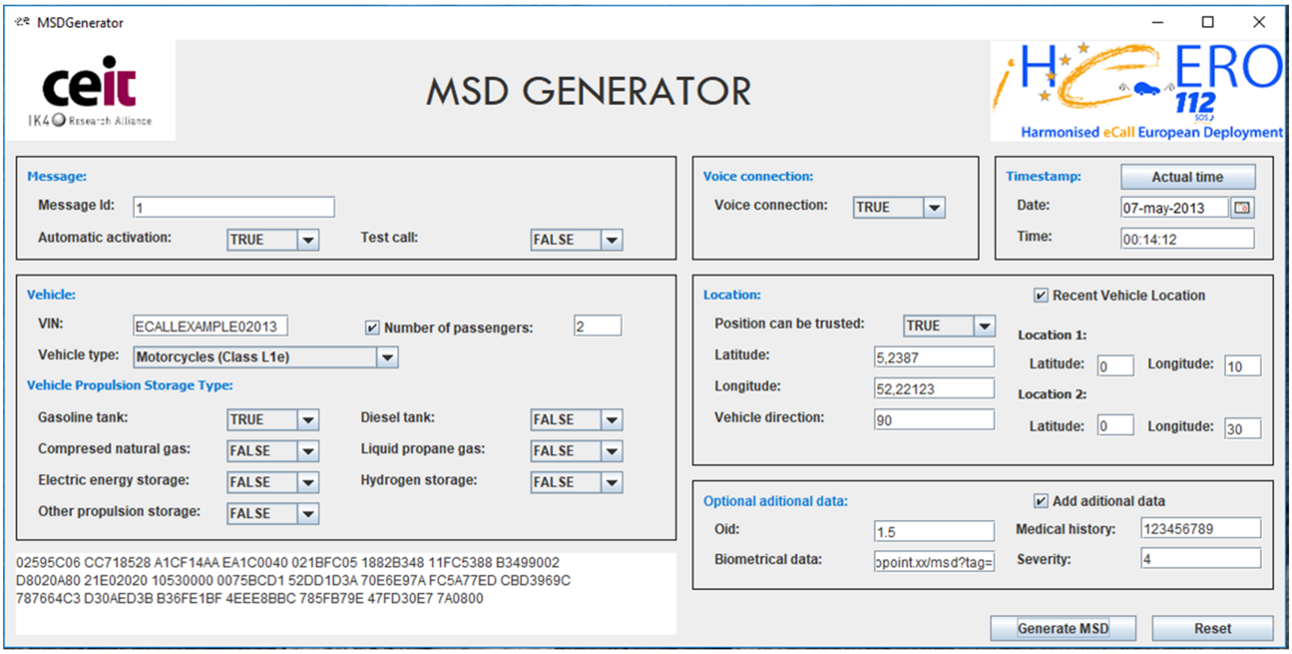

Figure 24: Host PC interface for MSD setting

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During the study of i_HeERO P2W cluster some parameters were defined useful for PSAP and rescue efficiency (highlighted on Figure 67):

- **Voice connection** present (true) or not present (false)
- **Number of passengers** (for P2W 1 or 2)
- **Medical history** defined in the national insurance number.
- **Biomedical data** if present some biomedical sensors
- **Severity level** as defined in the Activity 3.5.

The comparison of setting parameters, via Host-PC tool, and the parameters received, from the vehicle as MSD format, was proof that the eCall function worked correctly in all its parts.

2.6. Prototype testing

The riding tests were done on the test track of the BOSCH corporate research campus in Renningen. The riding tests were planned in a way to comply the basic requirement as defined in the i_HeERO consortium and the internal functional requirements.

2.6.1. Non-trigger Events

Extreme riding maneuver

A professional stunt rider was hired to conduct with both bikes accident-free riding with unusual excitations of the sensor set, i.e. wheelies, stoppies and drift maneuvers. The aim is to show at first that even under extreme conditions no eCall is triggered.

Figure 25: Examples for extreme riding maneuver

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Title: VM-156: Advanced Crash Detection for PTW eCall

Topple at stand still

To show that topple in stand still condition also don't trigger an eCall the KTM bike was overturned without a rider sitting on.

Figure 26: Example for topple at stand still

2.6.1. Trigger Events

Low-sider accident

Directly after the non-trigger maneuvers with the Aprilia, the stunt rider did intentionally a low-sider accident by strong braking of the front wheel with deactivated curve-ABS while curve riding with a velocity of ~60 km/h to demonstrate eCall triggering under realistic circumstances.

Figure 27: Example for low sider

Rear-end accident

A further accident type was a collision with a passenger car while standing still with the bike which corresponds to a typical crossing accident. Due to safety reasons, no rider was sitting on the bike. The KTM bike was equipped with side bags to avoid seizing with the car. The glass windshield of the car was laminated with an adhesive film to avoid fragmentation to safe the car driver and the airbags were disconnected. The stunt rider also drove the car wearing complete motorcycle safety gear and hit the motorcycle at rear-end with a velocity of 50 km/h.

Figure 28: Example of rear-end collision

These maneuvers can be regarded as a minimum demonstration set of extreme non-trigger situations and eCall relevant accident types.

3. Conclusions and Consequences

3.1. eCall system performance

The performed prototype tests showed a good performance of the complete on-board eCall system during the use case and misuse case tests. Nevertheless the system and algorithm has limitations. In the following the range and limitations of the algorithm and the system will be outpointed.

3.1.1. Covered cases & white spots of the algorithm

The test catalogue as well as the available database cover several cases of the daily usage, professional riding up to outstanding handling and maneuvers in riding and stand still situation. That guaranties a high level of robustness of the algorithm in trigger and non-trigger events.

However, for a serial application, a set of maneuvers would have to be tested and parameters applied:

- rough road and handling tests with the specific bike, maybe some application parameter have to be adapted to the type of bike (e.g. scooters, light-weight bikes and extreme heavy bikes)
- some low-relevant types of collision are still not tested or covered (e.g. opponents like pedestrians, bushes, scarps)
- motorcycles could be modified, i.e. with large side bags which may damp collision excitations or limits the lean angle in a final position situation

Definitely not covered are the following cases:

- light collisions (not reaching thresholds of *SituationDetection_CrashAcceleration*) at speeds higher than *eCall_v_min* with a upright final position, e.g. rider gets separated from the bike during a high sider while the bike gets softly stuck between small tress or bushes
- light collisions (not reaching thresholds of *SituationDetection_CrashAcceleration*) at speeds higher than *eCall_v_min without reaching a final position, e.g. bike got stuck in a train or trailer after a lowsider not noticed by the driver and continuous driving of the opponent keeps bike in motion.*

3.1.2. Hardware & connectivity performance

The complete hardware system composed of ABS ECU, MM5.10 IMU, CCU and SOS button was equipped on the two prototype motorcycles KTM 1290 Super Adventure R and Aprilia Tuono 1100 during the use case and misuse case tests which were performed by CR/AEV1. During the tests the system had to resist several rides over the rough road track on the Boxberg proofing ground, rough riding manoeuvre (e.g. Stoppies, wheelies, drifts) performed by a stunt rider and accidents (60kph lowsider, 50kph vehicle to vehicle collision).

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The connectivity itself was tested during several eCall test launches and during the performed test accidents.
During all tests the system performed correctly and reliable. Nevertheless, the components and the system architecture needs to be tested and if necessary optimized for crash resistance on higher speeds. One of the topics could be the guarantied time of power supply, strategy at disconnection of sensors or CAN link etc. in case of an accident.

3.2. Transfer to 2WP

The results of the project are transferred to the business unit 2WP in 12/2017. In the following the transfer objects and the necessary next steps are discussed.

3.2.1. Algorithm

The function is transferred in the ASCET module which contains the eCall algorithm as well as in a complete software for the ABS ECU for a KTM 1290 Super Adventure R. The software has prototypical status and needs to be reviewed and released by the corresponding experts of the 2WP/ESS team.

3.2.2. Prototype

A detailed documentation of the KTM 1290 Super Adventure R prototype which is shown in 2.5, is transferred.