From	Our Reference	Tel	Renningen
CR/AEV1	Florian Mayer	+49(711)811-6332	29 June 2017
CR/AEV1	Henzler Markus	+49(711)811-43433	Report Number
CR/AEV1	Skiera Alexander	+49(711)811-42035	1

R&D Report: **Study**

Security Class: Internal Export control relevant: No

Title: VM-156: Crash Detection for PTW eCall

Abstract

1. Issues (situation, motivation and tasks)

Starting point for this CR-Project VM-156 was the set-up of the public funded project (PFP) i_HeERO in 2015. The aim of the i_HeERO project is to derive the specific requirements for a PTW eCall system and in the end to give a proposal for eCall standardization and to point out the differences to the already existing approach for passenger cars.

VM-156 was set up to develop firstly, a Bosch PTW crash detection algorithm based on available hardware and propose the necessary verification and validation procedure. Secondly, a bike should be equipped with the developed prototype of an eCall system representing the defined requirements within the i_HeERO project. Further, the possibility to predict the severity of the biker and the potential of an eCall system is analysed. The project is funded by 2WP and the PFP i_HeERO.

Main goals for VM-156 and contributions to the public funded project i_HeERO within the 2 years development duration are:

1. Build up a manoeuvre database containing various sensor signals of relevant situations (crash, misuse, normal driving) [in 2016]
2. Conduct patent analysis for PTW crash detection and derive limitations for development [in 2016]
3. Set up simulation tool chain for crash calculation and creation of sensor signals [in 2016-2017]
4. Develop prototype of basic crash detection algorithm with minimum hardware requirements [in 2016]
5. Assess possibility of severity estimation in case of an accident [in 2016-2017]
6. Develop prototype of advanced crash detection algorithm which is adjustable in its trigger condition and levels [in 2017]
7. Develop a proposal for verification and validation of a PTW eCall system [in 2017]

2. Method

Basic idea for this development project was to set up a powered two-wheeler manoeuvre database (PTW-MDB) containing real sensor signals of various riding and accident situations. The crash detection algorithm for PTW was then developed and tested on this database using already existing hardware of the PTW product line. Any possible restrictions by patents for the developed algorithm solution were ruled out by a professional patent analysis. The developed

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algorithm will then be implemented into the ABS software and integrated into a bike for demonstration. In parallel, a simulation tool chain is in development, which should be able to simulate any bike accident and generate synthetic sensor signal data.

3. Results

During the considered project phase from 01/2016 until 04/2017 the following results were produced:

1. As most promising sensor, the MM5.10 was determined. The conducted patent research has shown that only usage of acceleration values is uncritical. Therefore, currently only the acceleration information is considered.
2. A maneuver database containing 711 maneuvers was set up. The maneuvers consists of PTW-vehicle-, PTW-object-collisions, single accidents and normal riding situations of various lengths.
3. A basic crash detection algorithm using only acceleration information was developed. The algorithm already archives a good detection performance and high robustness. It mainly consist of the detection of three crash phases (motion-, crash-, final position- detection) and their logical assessment within a state machine.
4. The correlation between severity probability for the rider and accident severity could be shown by simulation for three specific PTW-car collisions: PTW-front vs. car-side, PTW-front vs. car-front and PTW-side vs. car-front. The severity probability mainly depends on collision type, angle and velocity of the participants.
5. The simulation tool chain for PTW collisions and a first version of three different PTW-MKS-models was set up. The quality of the simulation has not reached the required performance yet.

4. Conclusion

The basic crash detection algorithm already provides a good performance and the maneuver database is a good basis for further development. However, the current concept is limited regarding adjustable trigger conditions and is not sensitive to specific situations. Therefore, for the second project phase the focus will be laid on extension of the current crash detection concept by using further sensor signals like wheel speed. By that, adjustable trigger levels for different situations should be achieved. A second topic will be to develop a general verification and validation procedure of the algorithm for a later serial development. Additionally, the suitability of the simulation tool chain for further development projects will be finally assessed.

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Document approval			
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Crash detection, fall detection, PTW, eCall, MM5.10, multi body simulation, crash simulation, PC Crash, i_HeERO

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Long Version

5. Issues (situation, motivation and tasks)

OEMs are interested in new active and passive safety technology as well as connectivity products. One of the OEM's requests is to provide an eCall system to their customers. In parallel a public funded project (PFP) cluster called i_HeERO is running from 2015 until 2017. This project deals among other things with the special requirements for a PTW eCall system and aims in the end to give a proposal for eCall standardization and to point out the differences to the already existing approach for passenger cars.

An eCall system for PTW differs significantly from the one of passenger cars. Firstly, for passenger car the eCall triggering criteria is mainly provided by the already existing airbag triggering signal. This leads to a low development effort for the integration of the eCall system and no new crash detection concept is needed. For PTW such a reusable triggering mechanism, which works for every collision, does not yet exist. Therefore, a new concept has to be developed, dealing also with the special behaviour of a single-track vehicle. Secondly, for passenger car, occupants and vehicle form one unit and are connect via seatbelts to each other. This means in case of a crash event, the severity of the crash is directly correlated with the injury severity of the occupants. For PTW the picture looks quite differently. Rider and bike are only lightly connected. In case of a collision, rider and bike are uncoupled and therefore do not necessarily experience the same physical loads. This makes it very challenging to estimate an expected severity and base the decision to trigger an eCall on that.

The Bosch PTW product line already contains inertial sensor like MM5.10, ABS and MSC systems and a communication unit (CCU). However, a crash detection algorithm from Bosch for a PTW eCall system is missing.
VM-156 was set up to develop firstly, a Bosch PTW crash detection algorithm based on available hardware and propose the necessary verification and validation procedure. Secondly, a bike should be equipped with the developed prototype of an eCall system representing the defined requirements within the i_HeERO project. Further, the possibility to predict the severity of the biker and the potential of an eCall system is analysed. The project is funded by 2WP and the PFP i_HeERO and is set up for 2 years from 2016 until 2017.

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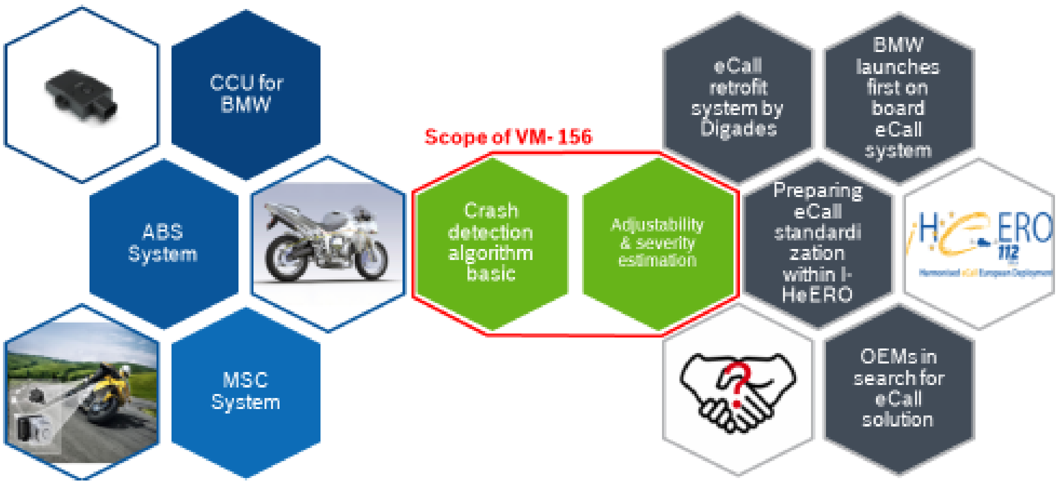

Figure 1: Scope of VM-156: Close eCall gap between Bosch and costumer

Main goals for VM-156 within the 2 years project duration are:

1. Build up a manoeuvre database
   The manoeuvre database should be the basis for the crash detection algorithm development. The covered manoeuvres should contain crashes, such as single accidents, PTW to vehicle accidents and PTW to object accidents, misuse cases like toppling and normal driving journeys. The manoeuvres are catalogued and described by measured sensor signals. The type of sensor signals can be of acceleration-, gyro- or wheel-speed-sensors from multiple bike positions, different bike types and various sensor specifications. For some accidents, also sensor signals of the rider are available.
   [in 2016]
2. Conduct patent analysis for PTW crash detection and derive limitations for development [in 2016]
3. Set up simulation tool chain for crash calculation and creation of sensor signals [in 2016-2017]
4. Develop prototype of basic crash detection algorithm with minimum hardware requirements [in 2016]
5. Assess possibility of severity estimation in case of an accident [in 2016-2017]
6. Develop prototype of advanced crash detection algorithm, which is adjustable in its trigger condition and levels [in 2017]
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6. Method

One of the development boundaries is to reuse already existing hardware of the PTW product line. Therefore starting point was to get an overview of existing inertial sensors, there performance and available signal data of crash events or normal riding. At the same time an accidents analysis of the German in depth accident study (GIDAS) database was conducted to identify the most relevant accident scenarios for PTW. In addition, a patent analysis (freedom to operate research) conducted by CIP was ordered to reveal possible solution which are already covered by patents. Combining these information sources, a first concept for crash detection with minimum hardware requirements was developed.

As next step, available signal data of crash events or normal riding within Bosch were collected, rehashed and integrated into a newly set up powered two-wheeler manoeuvre database (PTW-MDB). The idea behind this manoeuvre database is to have a well-described source, which could be used for any future algorithm development using the same signals. To cover also collision where no data are available, it is tried to set up a simulation tool chain based on multi body simulation (MKS), which should be able to simulate any PTW-vehicle or object collision and generate inertial sensor signals of the various bodies.

Using the PTW-MDB the algorithm concept was implemented, tested and adjusted based on the performance on the database. As next step, the algorithm should be extended so that it is not only possible to detect a crash event but also to classify it. By that, an adjustable algorithm with extended functionality should be achieved.

Furthermore, it should be assessed, if a severity prediction of the rider in case of a collision based on inertial sensors only is possible. Therefore, certain PTW-vehicle accidents are simulated and the resulting physical loads calculated. Using these loads the injury probability is calculated and by variation simulation general mathematic correlations between physical loads and injury probability are determined.

Finally, a general verification and validation proposal for PTW crash detection algorithm will be derived using the PTW-MDB as one component.

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7. Results

In the following, we describe our development procedure and discuss the performance of our current algorithm concept.
Starting point is the accident situation for powered two-wheeler followed by the results of the patent analysis. Then the PTW manoeuvre database is described as well as a short status overview of the simulation tool chain is given. A special focus is laid on the development procedure of the algorithm and the performance assessment. Finally, a short overview of the i_HeERO project is given.

7.1. PTW accident situation

To develop a system with high field effectiveness, an analysis of the accident situation for PTW in Germany was conducted. The results provide information about the most frequent accident types and the crash constellation of PTWs. Using further information of these accidents like the final position, a first detection concept was derived.

The federal statistical office of Germany (DeSTATIS) provides every year a detailed report about the current accident situation in Germany containing all accident with casualties collected by the police. According to this report, PTWs (L1 & L3) are involved in 14,1% of all accidents with casualties in Germany in 2013.
The information depth of the DeSTATIS information is only limited, therefore the German in depth accident study (GIDAS) was used for further analysis. The GIDAS data contain accidents with casualties from the area of Dresden and Hannover. The data are available within Bosch from 2000 onward and contain detailed pictures of the accident, reconstructed information as well as 2.000 – 3.000 coded attributes about every accident.

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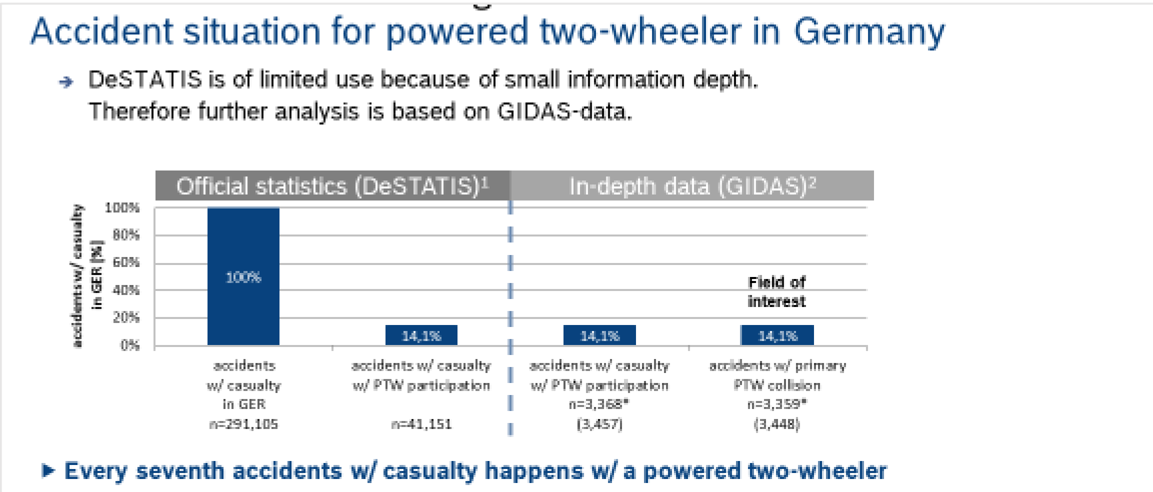

Figure 2: PTW accident situation in Germany in 2013

For an eCall system, accident situations where the PTW is the only involved party are of special interest, as in these cases it is not insured that the rider or someone else can make the emergency call. In Germany in about 26% of all PTW accidents with casualties, the PTW is the only involved party. In the remaining 74% at least one other party was involved.

Looking at the direction of force taking effect during the first collision on the PTW, it can be seen that in most cases the force is directed to the front part. Forces to the PTW sides are nearly equally distributed between left and right. Forces from the rear are very rare in single accidents and occur significantly less frequently than in accidents where other parties are involved.

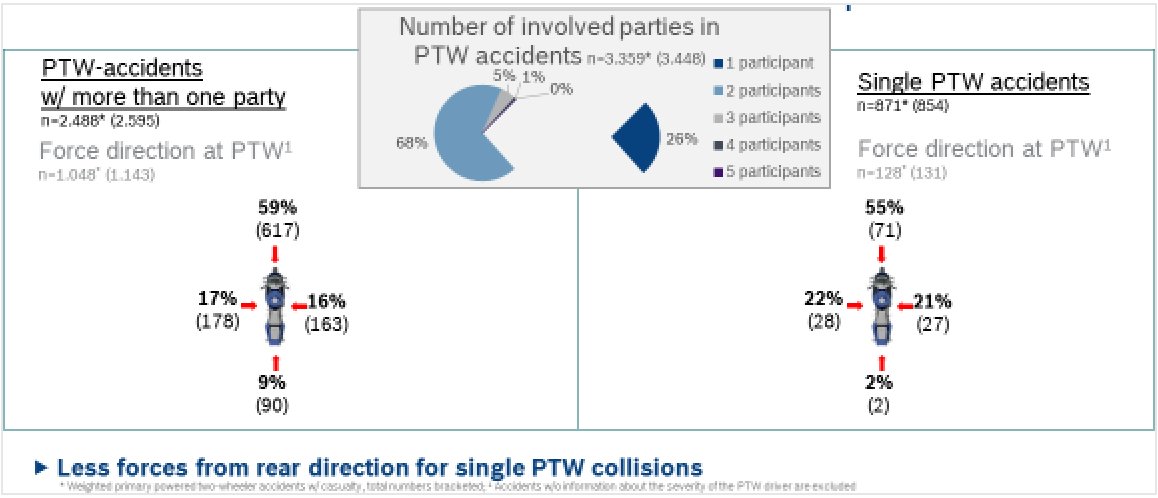

Figure 3: PTW accident w/ casualties in Germany. Direction of main collision force on PTW for single and multi-party accidents.

As part of the public funded project i_HeERO the accident research company VUFO (Verkehrsunfallforschung Dresden) was charged to analyse the most frequent PTW accident constellations and their severity. This analysis is also based on GIDAS data but limited to L3 bikes. To identify relevant accident scenarios and severity following injury severity levels were used.

Injury Severity (IS) 4:	Fatal (died within 30 days)
Injury Severity (IS) 3:	Severe (hospitalisation > 24h)
Injury Severity (IS) 2:	Slight, with hospitalisation (< 24h)
Injury Severity (IS) 1:	Slight, without hospitalisation
Injury Severity (IS) 0:	No injuries

Figure 4: Injury severity levels [i_HeERO project results]

The member of the i_HeERO project decided to define all accidents where the rider was taken to hospital as eCall relevant, as is these cases the rider needed treatment of its injuries.

Injury Severity	IS4	eCall is necessary
	IS3	
	IS2	
	IS1	eCall can be necessary
	IS0	eCall not necessary

Figure 5: Triggering requirement, User [i_HeERO project results]

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As result, fourteen constellations where identified which cover 90% of all PTW accidents with casualties in Germany. 43% of all PTW accidents are against a passenger car and 26% while riding a curve. According to this analysis, the two most frequent scenarios are a single bike, which is driving straight and falling, and a front-front collision between bike and car. For each accident constellation the relevance for different severity levels is also given.

Use-case	Description	Further distinction	Accidents	% of all PTW accidents	% of all IS 0	% of all IS 0-1	% of all IS 2-4	% of all IS 3-4
1a	Collision with a car (DS, DC, SS)	PTW: front Car: side	2.546	12.8%	3.8%	11.9%	13.0%	13.2%
1b		PTW: front Car: front	1.594	8.0%	1.2%	3.4%	9.2%	11.3%
1c		PTW: side/front Car: side	1.502	7.5%	2.5%	10.2%	6.8%	6.5%
1d		PTW: front Car: rear end	1.188	6.0%	3.6%	7.4%	5.6%	5.3%
1e		PTW: side Car: front/rear	716	3.6%	0.0%	3.8%	3.5%	3.1%
1f		PTW: rear end car: front	645	3.2%	3.2%	7.1%	2.2%	1.5%
1g		PTW: side car: edge	461	2.3%	0.0%	2.3%	2.3%	2.2%
2a	Braking and fall	Driving straight	3.667	18.4%	11.6%	20.3%	17.9%	13.0%
2b		Driving curved	2.048	10.3%	2.9%	5.6%	11.5%	13.9%
3a	Collision with an object	Driving curved	1249	6.3%	0.0%	1.9%	7.4%	9.1%
3b		Driving straight	696	3.5%	1.9%	1.2%	4.1%	3.8%
4a	Collision w/ ped./ bic./ ani.*	Driving straight	880	4.4%	26.6%	9.6%	3.1%	4.0%
~~4b~~		~~Driving curved~~	~~159~~	~~0.8%~~	~~12.1%~~	~~2.5%~~	~~0.4%~~	~~0.3%~~
5a	Constant ride and fall	Driving straight	417	2.1%	3.5%	1.2%	2.3%	1.4%
5b		Driving curved	215	1.1%	1.3%	0.2%	1.3%	2.2%
15 proposed USE-CASES			17.983	90.2%	74.1%	88.5%	90.6%	90.6%
ALL P2W accidents (total numbers)			19.946	19.946	688	4.112	15.834	6.924

Figure 6 Most frequent accident constellations for Motorcycles (L3) [i_HeERO project results]

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7.2. Patent analysis

A freedom to operate research was conducted by C/IP to point out possible limitations for the PTW crash detection. Several solutions and methods turned out to already be protected. Especially if turn rates are used, possible patent infringements have to be carefully considered.

The focus of the patent research was laid on systems, which are using acceleration or turn rates for crash detection in powered two-wheelers. In total, 75 relevant patents could be identified. Out of that, 29 where rated as potentially critical.

The critical patents where analysed in detail and possible restriction for further product design were identified.

Finally, seven IPs are rated as highly relevant and following possible restrictions have to be considered for system development:

- EP 2 026 287 A2 (EP, JP) → Kawasaki Heavy Industries
  Using event data recorder for critical events
- EP 20 79 613 B1 (EP, WO) → Dainese S.p.A.
  Using angular speed for fall detection/prediction
- EP 2 632 772 B1 (EP, US, JP) → Dainese S.p.A.
  Using calculation of energy term for detection
- US 6,496,763 B2 (US only) → BMW
  Using wheel speeds to detect rollover signal
- EP 1 184 233 B1 (EP, US, JP) → Yamaha Motors
  Using sensor & control unit in one hardware
- EP 22 68 507 B1 (EP) → Meta System SPA
  Using electronic siren for alert function / reaction of rider
- US 8 860 570 B2 (US only) → Sense Tech (ICEdot)
  Using angular velocity for detection

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<u>Freedom to Operate:</u>

- 75 Patents are assessed
- 29 rated as relevant

Final approval by C/IPE-Dep.

<u>Restriction of the research:</u>

- Markets: no limit, but focus on DE, EP, WO, US, (JP *)
- Focus: procedure for crash detection (not on hard solution)
- Assumption: onboard system (acceleration & gyro)

<u>Planned action:</u>

- No need

<u>Situation detection status:</u>

- Low risk for current algorithm concept!
- Risks for product design & adaptions to algorithm are identified!

→ <u>Potential risk for using algorithm directly in MM5.10 sensor!</u>

Out of the patent analysis, we conclude that using acceleration sensors for crash detection bears no risk, whereas using turn rates it could be challenging not to infringe with any patents. It should also be ensured that the crash detection algorithm is not directly calculated on the sensor unit but separately.

In any case, for the final solution for serial production, a separate patent research has to be conducted to avoid any infringements.

7.3. Available signal data

For the crash detection development, it is of high importance to have a large set of crash signals and non-crash signals available. As crash test are very costly, reuse of already available data is preferred. Therefore, the first step is as research within Bosch for PTW crash signal data.

Within the Bosch MDS database, several PTW-vehicle collisions and many misuse cases are available. Unfortunately, the data contain only accelerations measurements of the tests and limited documentations.

We also found several low- and high-sider measurements form MotoGP containing beside accelerations measurements also turn rates and CAN measurements.

DEKRA also sells crash test data from various crash configurations. These data are limited to acceleration signals only.

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Within CR, several low-sider accidents from another development project containing acceleration and turn rate signals are available.

As no other source for a large amount of crash data could be found, it was decided to take the available data and to focus on a solution based on acceleration signals. This decision is also in line with the results of the patent analysis to avoid possible restrictions by using turn rates.

7.4. Manoeuvre database

The idea behind the manoeuvre database for PTWs (PTW-MDB) is to have a generic structure for manoeuvres and their signals for any further function development. Any acquired or collected signals should be added to this database in the future. The database should include various manoeuvre like single accidents and PTW-vehicle crashes, but also normal riding manoeuvres like riding over a kerbstone. The variation should not only be present in terms of the kind of manoeuvres tested, but also in the used vehicle types. By that, the PTW-MDB should achieve a representative picture of the accident and riding situation of the real world. In the future, it would be desirable to extend the PTW-MDB also with simulate data of high quality to make it more comprehensive.

For setting up the manoeuvre database, we collected all available data within Bosch. Then we compared the available signals, sensor-mounting positions, signal quality, signal range, signal frequency.
Within Bosch, the MM5.10 sensor box is currently sold for PTWs. As the reuse of already existing PTW components is one of the project boundaries, we decided to transform all collected data to the specification of a MM5.10 sensor. In other words, the signals of every manoeuvre included in the database is also available from point of view of a hypothetical MM5.10 sensor. For the specific procedure of data transformation, filtering and integration into the database a separate documentation is available.
At the point of time of this report, the PTW-MDB contained 711 manoeuvres, whereof 61 are crashes and the rest are special riding situations like riding over cobblestone, speed bumps or bikes falling over. Several manoeuvres from the MDS database were deleted because of implausible signal behaviour. Out of the 61 available crashes, 27 crashes also include turn rate signals.

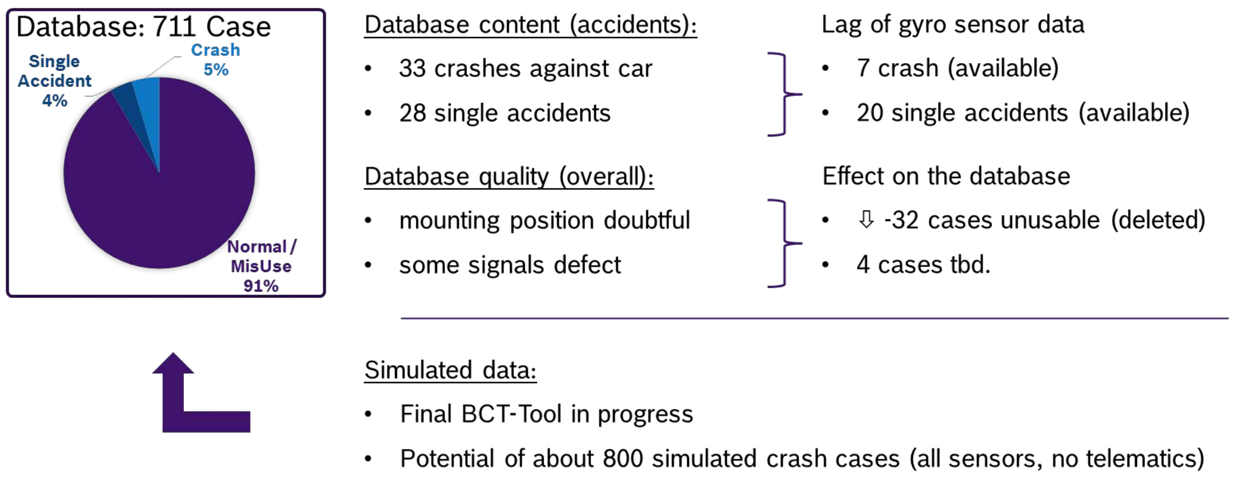

Figure 7: Content of PTW-manoeuvre database (PTW-MDB)

To be able to select specific manoeuvres we set up a reference document, which includes the following additional information of each manoeuvre:

- **Category:** short description of the manoeuvres
- **Status:** status of the signal processing
- **Name:** filename
- **Bike Speed:** bike speed as far as documented, partly also opponent vehicle speed
- **Description:** detailed description of the manoeuvres
- **Source:** original source of the file
- **Confidential:** information about possibility to share/show extern
- **Original Name:** original filename from source
- **Sim/Real:** signals based on simulation or real tests
- **Crash:** is the manoeuvre a collision (e.g. vehicle or object)
- **Single Accident:** is the manoeuvre a single accident (e.g. low sider)
- **Pre-Crash-Phase:** is pre-crash phase recorded or not
- **Crash-Phase:** is crash phase recorded or not
- **Final-Phase:** is final position in post-crash phase recorded or not
- **ISO Crash Code:** crash constellation based on ISO 13232
- **Situation or Algo Verification:** preferred use of the file
- **Bike or Scooter:** type of used vehicle
- **Original Sampling Rate:** sampling rate of the original file
- **Acc High G Fork:** equipped sensors

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- **Acc High G Chassis:** equipped sensors
- **Acc Low G Chassis:** equipped sensors
- **Turn Rate Chassis:** equipped sensors
- **Velocity:** equipped sensors

To extend the PTW-MDB by missing manoeuvres, we bought not only crash test data from DEKRA, but also conducted and are planning again our own crash tests. Additionally several off-road rides and manoeuvre tests were performed or are planned.
The manoeuvre database is intended to be a living object. We would like to extend it further by all relevant data we can find and which meet the minimum requirements for integration.

7.5. Simulation tool chain

As mentioned before, it would be desirable to be able to simulate any PTW accident and generate sensor signals and thereby avoid costly crash tests. Currently, there is no software available, which provides both the crash simulation and the required validated PTW models.
Therefore, it is attempted within this project to come up with an original solution, which provides a good compromise between accuracy of the signals, calculation effort and usability.

As simulation core PC-Crash was chosen. PC-Crash is a software originally developed for reconstruction of accidents and constantly extended by new functions. Thereby, PC-Crash is also able to calculate accidents using multi body systems (MKS).

For the development, the following major steps have to be performed:

- Development of new multi body systems for different PTW types and correct parameterization by comparing real crash signals with simulated ones.
- Automatic crash calculation of several accidents and signal exportation.

As competence and capacity for the development within this project were missing, the tasks to develop a new simulation framework (Bosch converter toolkit (BCT)) and to create valid MKS-PTW models were given to Fraunhofer Institut (IVI) in Dresden.

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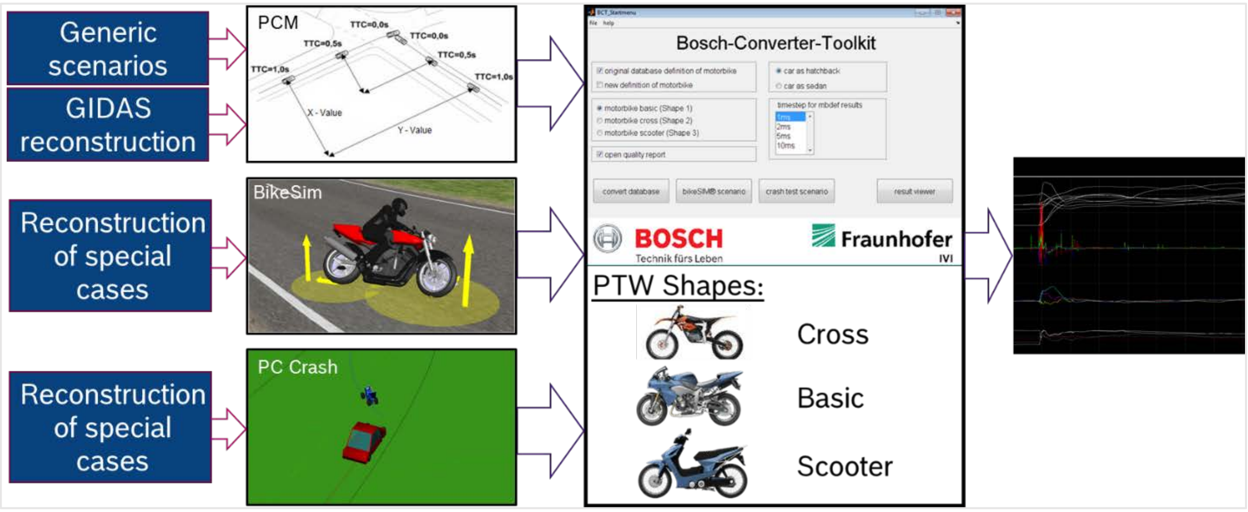

Figure 8 Overall framework of simulation tool chain (BCT) and their plugins

At point of time of this report, the BCT is set up completely. However, the MKS models do not meet the required performance. Firstly, some implausible kinematic behaviours of the bike or rider for some situations can be observed. Secondly, the sensor signals are not in a comparable range to real crash data.

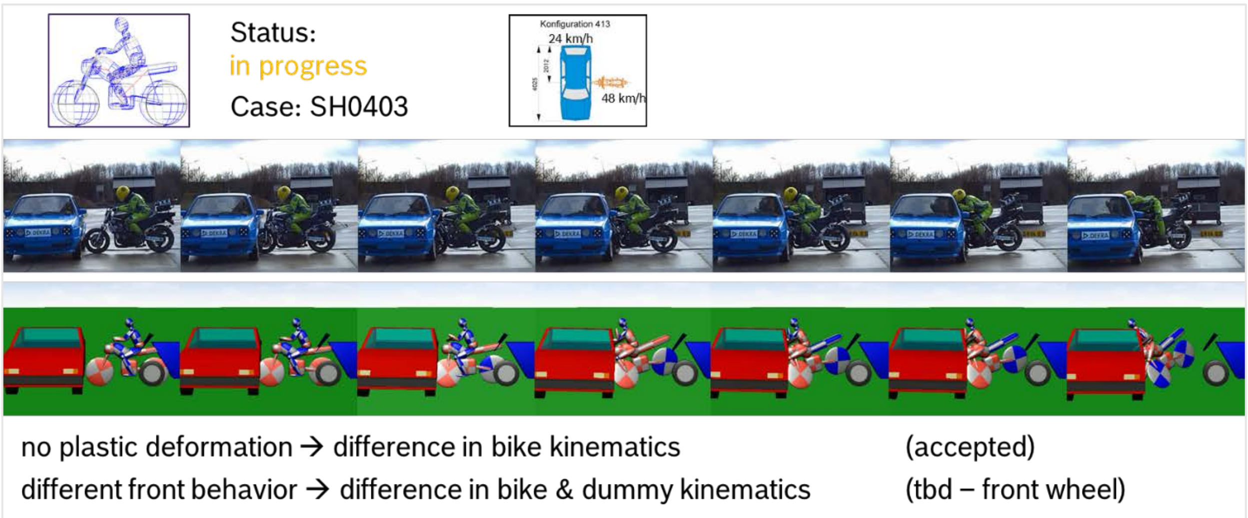

Figure 9 Kinematic comparison between simulation and real crash test.

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During the remaining time of this project, we will analyse, if, by adjusting the MKS models, a reasonable quality can be achieved and thus the tool chain can be used for further developments.

7.6. Algorithm development

This project focused in its first phase to develop a simple but robust crash detection algorithm, further on called basic algorithm. The development process was set up in five steps.

1. Identify relevant crash scenarios (use cases) and critical driving events (misuse cases) for a possible algorithm.
2. Deriving a first detection concept based on the defined use and misuse cases.
3. Implementing a first version of the detection concept into Matlab and test it on the manoeuvre database. Thereby identifying critical Use and Misuse cases for the algorithm.
4. Increase robustness of algorithm by optimized trigger strategies and retesting on manoeuvre database and endurance runs.
5. Final performance assessment and transfer to 2WP.

In the following, the development procedure as well as the algorithm will be described in detail.

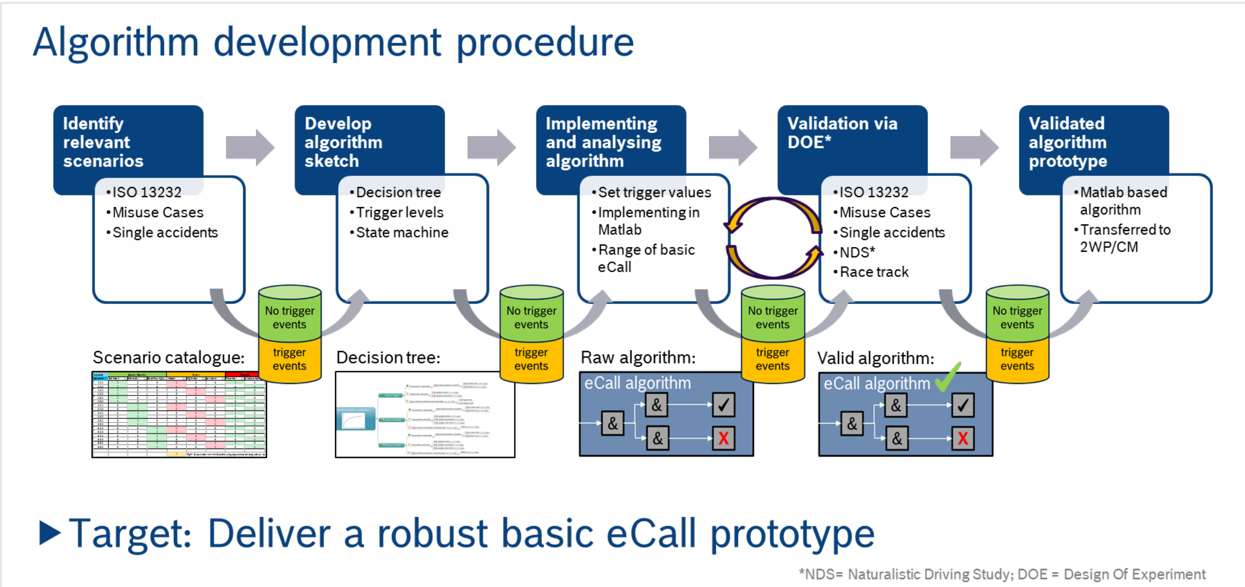

Figure 10: Algorithm development procedure for PTW crash detection

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7.6.1. Identify relevant scenarios

In the accident analysis section (PTW accident situation) the most frequent accident scenarios were already introduced. Accidents with higher speeds and/ or high impact can be generally seen as use cases for an eCall system. However, there are still some cases where there is no easy decision between use or misuse case. Such cases could be for example a toppling bike at stand still or hitting a car with a velocity below 10kph. We expect that the OEM will define the triggering of an eCall in such cases.

Misuse cases are defined as all situation where no eCall triggering is requested. This includes every normal riding, wheelies, stoppies, the bike being transported and, depending on the OEM's decision, low speed accidents.

For setting up use and misuse case catalogs, we mainly reused the already available catalogue from the PTW airbag development project. This catalogue contains already a huge amount of possible misuse cases.

Normal Ride Test Catalog (Full)

Crash-Code/Description	Speed-dependent	Critical Speed [km/h]	Speed Range available	UFO relevance	Peak_Values_Ax_Extd	Peak_Values_Ay_Extd	Peak_Values_Az_Extd	Peak_Values_Ax_MM510	Peak_Values_Ay_MM510	Peak_Values_Az_MM510	Candidate4Validation
Accelerate from center stand	No	0	0	0	22	31	56	1	1	14	
Acceleration, µ-high to µ-low	No	0	0	0	12	17	34	3	2	3	
Acceleration, µ-low to µ-high	No	0	0	0	19	25	82	3	1	5	
Acceleration, 50km/h up to Vmax	No	0	0	0	24	34	71	2	2	6	
Against wall, low speed (6-10km/h)	Yes	7	<10	0	139	932	798	41	24	41	x
Banked curve	Yes	NA	NA	0	NA	NA	NA	NA	NA	NA	???
Brake, µ-high to µ-low	No	0	0	0	19	25	68	3	2	13	
Brake, µ-low to µ-high	No	0	0	0	27	42	76	3	2	14	
Brake, ABS assisted to standstill	No	0	0	0	16	23	79	3	3	12	
Bump	Yes	80	<110	0	337	971	823	38	41	41	x
Burnout, to drive	No	0	0	0	21	30	65	4	4	11	
Burnout, to standstill	No	0	0	0	24	31	64	3	3	20	
Chuckholes, different types	Yes	30	<50	0	507	1022	1006	41	41	41	x
Concrete platform (also in a row)	Yes	50	<50	0	435	1015	1022	41	35	41	x
Corrugation	Yes	70-80	<130	0	121	298	198	16	17	41	
Crossbar, different angles	Yes	50	<80	0	86	45	47	24	12	24	
Curbstone, different sizes, down	Yes	45	<50	0	35	65	121	4	7	8	
Curbstone, different sizes, up	Yes	45	<50	0	3026	995	1164	41	41	41	x
Dis-/Assembly half axle (with hammer)	No	0	0	0	125	250	454	1	2	3	
Dis-/Assembly wheel nut (with wheel gun)	No	0	0	0	9	18	28	1	1	1	
Groove	Yes	0	<80	0	34	29	52	16	9	9	
Handlebar Vibration	No	0	50	0	23	20	48	3	14	16	
Handling, centre stand	No	0	0	0	10	18	64	2	1	14	
Handling, equipment (e.g. case)	No	0	0	0	4	6	23	0	1	11	
Handling, handle bar (also strong up to the stop)	No	0	0	0	9	24	54	1	2	12	
Handling, jacking up and down	No	0	0	0	18	21	47	1	1	12	
Handling, seat bench	No	0	0	0	41	66	170	1	5	15	
Handling, side stand	No	0	0	0	NA	NA	NA	NA	NA	NA	???
Handling, transportation	No	0	0	0	4	5	21	1	1	14	
Iron ladder	Yes	50	<50	0	198	218	723	41	41	41	x
Jump, different height	Yes	100-110	<120	0	400	1340	1066	41	32	41	x
Offroad trail	No	0	0	0	39	35	93	28	41	41	x
Pavement	Yes	60-80	<130	0	572	1039	899	41	41	41	x
Pothole, different sizes & types	Yes	40	<80	0	2310	1708	2823	41	41	41	x
Railroad Tie	Yes	35	<130	0	366	821	543	41	34	41	x
Railroad Track	Yes	0	<80	0	487	238	629	41	26	41	x
Ramp minus, 150mm	Yes	30-40	<50	0	102	221	341	19	37	41	
Ramp plus, 100mm	Yes	30-50	<70	0	1012	1017	1018	41	41	41	x
Resonance lane	Yes	90-100	<100	0	205	242	513	32	28	41	
River bead	Yes	30-50	<70	0	589	1028	1017	41	41	41	x
Sliding/Drift, x°/s²	Yes	NA	NA	0	84	138	216	25	16	36	
Square timber, 10cm	Yes	0	<60	0	1328	1861	1433	41	41	41	x
Stairs, down	No	0	0	0	118	273	270	20	7	41	
Tire	No	0	0	0	19	35	81	2	5	20	
Topple	No	0	0	0	219	318	423	6	22	19	
Washboard	Yes	>50	<80	0	344	213	153	24	17	24	
Waves	Yes	0	<80	0	74	75	178	11	12	14	
Wheely	No	0	<50	0	492	278	586	41	18	41	x
Longterm	No	0	0	0	0	0	0	30	41	41	x
Uphill + brake	Yes	0	<75	0	NA	NA	NA	NA	NA	NA	???
Downhill + brake	Yes	0	<75	0	NA	NA	NA	NA	NA	NA	???

Figure 11: List of misuse cases for an eCall system

Again, from the airbag development project, we also took some of our defined use cases. Additionally, we added several low / high sider accidents and further crash scenarios like rail guard accidents.

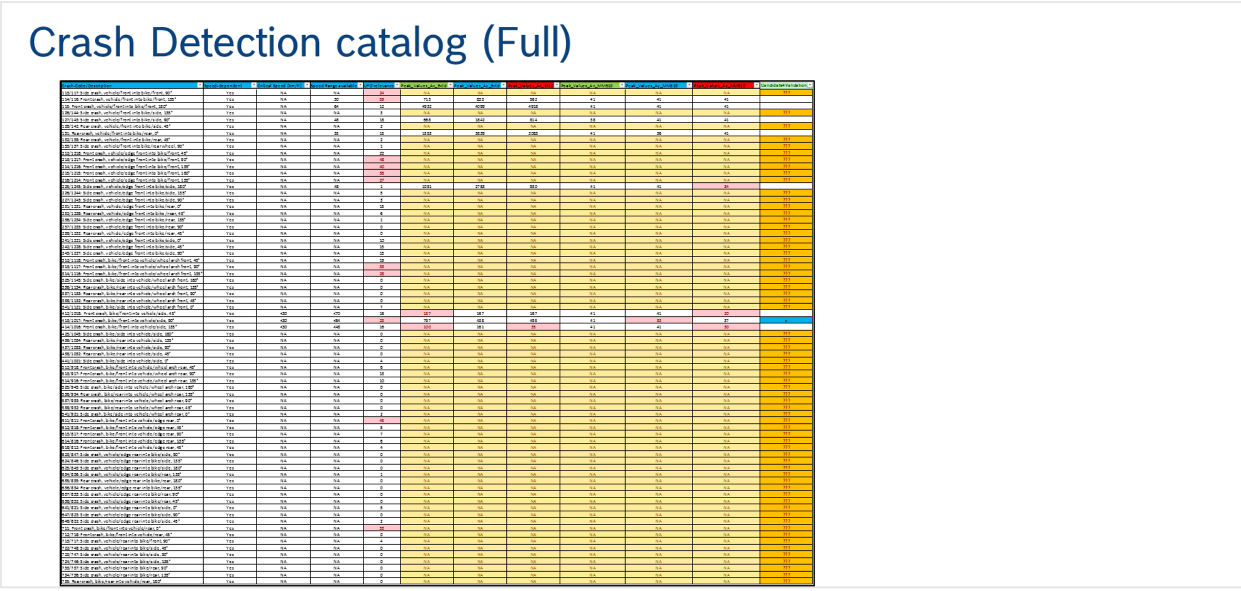

Figure 12: List of use cases for an eCall system

Having this catalogue at hand, we now knew which situations there are, which we want to trigger and where we do not want to trigger our system. The next step then was to develop a triggering strategy, which fulfills these requirements in respect to the given boundaries.

7.6.2. Development of algorithm concept

Looking at the use cases for PTW eCall an expectation of two-wheeled vehicles is that most come to rest on their sides after a collision. An acceleration sensor at stand still can easily detect this particular status.

Unfortunately, not all use cases can be covered by this criterion. There are some cases, where the motorcycle stands upright after collision. Either, because it is stuck in another vehicle or it is leaning on something. For some of these cases the acceleration peak during crash is a sufficiently distinguishing characteristic.

The idea now was to build up two separate classification blocks to identify use cases. One is trying to classify a lying PTW, the other one is trying to classify directly the crash event. To address also misuse cases, we added a third classification block, which detects normal motion of a bike. The advantage of different classification parts is that every part can be optimized separately. Such a structure is also open for extensions by further classifiers to meet additional upcoming requirements.

The three classifed situations are then planned to be logically assessed within a state machine. In this state machine the decision about triggering an eCall is finally made.

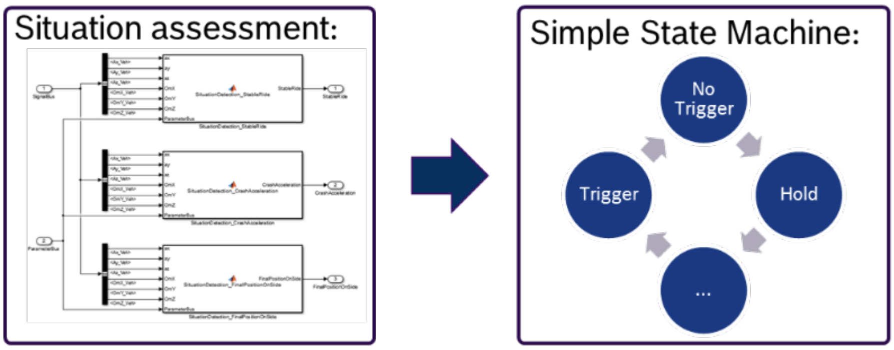

Figure 13: Modules of crash detection algorithm

7.6.3. Implementing and analyzing algorithm

As development framework, Matlab Simulink is used. Firstly, the algorithm is implemented. Secondly, it is tested on the PTW-MDB and the performance assessed. After the first two steps, the classification method and algorithm's parameters were optimized continuously. In the following, the status of the algorithm is described.

7.6.3.1. Normal ride classification:

The feature for normal ride is a rudimental motion detection by monitoring the resultant acceleration signal of all three axis. The PT1 filtered signal needs to show a change in the signal sequence of at least 2% in each timestep i.

Bike in motion: $\left|\frac{|a_{i+1}|-|a_i|}{|a_i|}\right| \geq 0.02$

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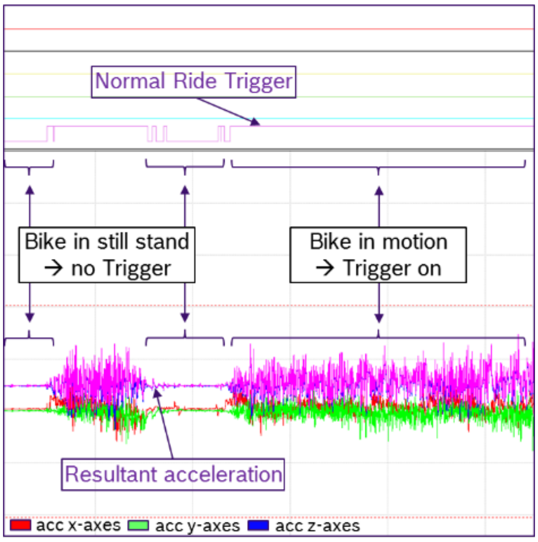

Figure 14: Signals of an endurance run with normal ride classification

Normal rider classification is currently a simple plausibility check in the state machine and will be extended by implementing the bike speed in the next generation of algorithm.

7.6.3.2. Crash/ collision classification

The feature for collision detection is a time depending monitoring of a threshold on the X- & Y-axis of the acceleration sensor. Because of limited acceleration sensor range of the MM5.10, it is not possible to separate collisions and rough riding manoeuvres by simply defining maximum peak values. The sensor is digital limited at 4.2g that cuts of the original peak during the time the signal is above this threshold. A suitable proxy parameter is the time above the threshold, which is related to transfer of momentum.

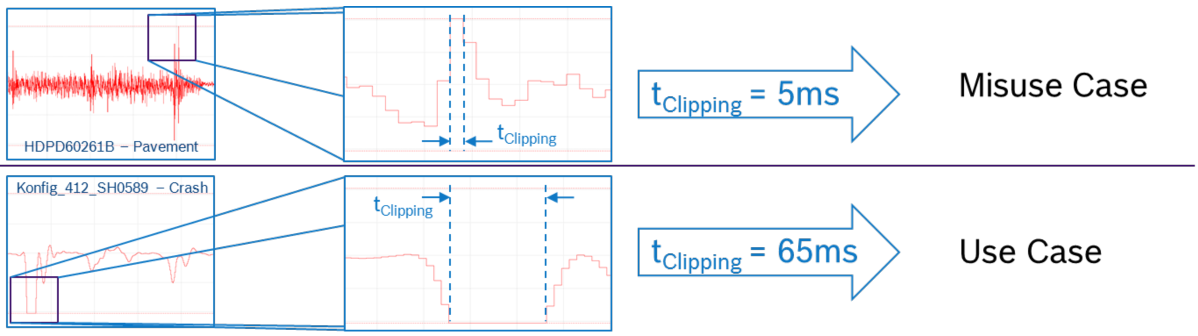

Figure 15: Comparison between time in clipping for use and misuse case

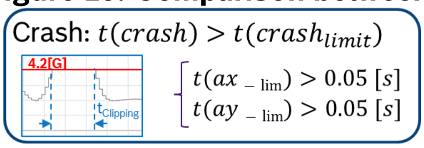

Figure 16: Mathematical description of crash classification

The current version is using a fixed acceleration threshold at 4.18g and a fixed time threshold of 50ms with sampling time of 10ms of the BUS-system of the axis x and y. The two thresholds are disjointed. For more precise separation of collisions and regular riding, the collision detection will be extended by speed depending thresholds in the next generation of algorithm.

7.6.3.3. Final position classification

To detect any implausible position of the bike while it is at stand still, the acceleration signal on Y-and Z-axis is monitored. The thresholds of the axis are defined as followed:

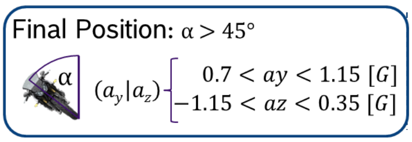

Figure 17: Mathematical description of final position classification

The thresholds are set such that the bike “normal position” has a lean angle of less than 45° or the vehicle z-axis is not more than 70° tilted compared to a bike in upright position. Here again the two criteria are disjointed.

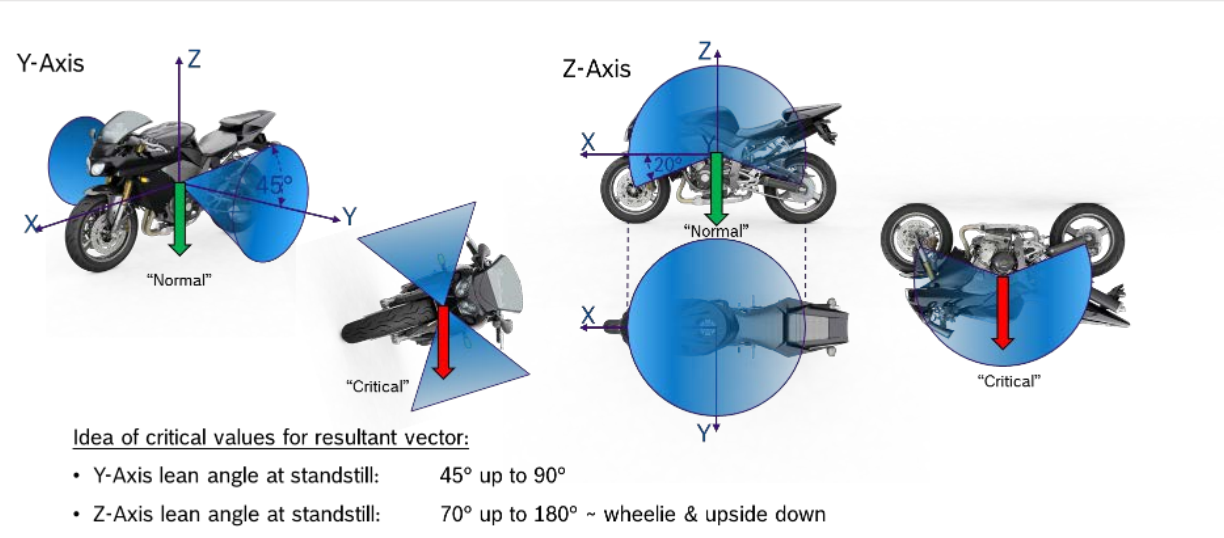

Figure 18: Leaning range for normal and critical classification

7.6.3.4. State machine

The state machine implements a logical assessment of the information delivered by the classifiers. The classifiers deliver every 10 ms following Boolean information:

- Normal ride classifier:
  - True → Riding detected
  - False→ No movement detected
- Crash/ collision classifier:
  - True → Crash/ collision detected
  - False→ No crash/ collision detected
- Final position classifier:
  - True → Bike on its side detected
  - False→ Bike is upright

The state machine consist of three conditions: Stable, Wait, eCall. Stable is the condition where the state machine should be while in normal riding. In case of a collision, there are two options. Either the impact was strong enough such that the crash classifier detects the crash directly. In this case, the state machine immediately changes its status to eCall and sends out the trigger. Otherwise, as soon as the bike has come to a standstill and is lying on its side, the state machine changes to Wait condition triggered by Final Position classifier. If for 1 second, the Final Position

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classifier stays true and the Normal Ride classifier stays false, the state machine changes to eCall. Also during condition of Wait, the Crash classifier has highest priority and directly forces a change of the state machine to the condition of eCall.

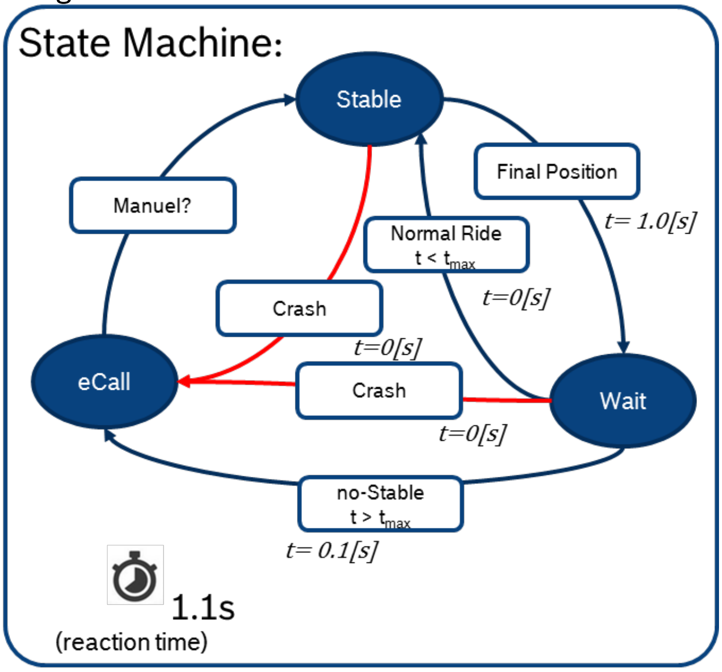

Figure 19: Statuses within the stat machine

The shown solution is the first basic version of crash detection algorithm and needs to be extended in the next generation of crash detection algorithm to meet additional demands for potential product, e.g. detect topple at stand still as misuse case.

7.7. Algorithm assessment

In this section, the algorithm test procedure using the PTW-MDB is described and limitations of the current concept are pointed out.

To assess the performance of the current algorithm concept, we performed a software in the loop test using the PTW-MDB signals as input. The manoeuvre are pre-defined as use or misuse cases in the PTW-MDB reference document. This categorization is then compared with the automatic assessment of the crash detection algorithm.

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At the moment of this test, there were 711 manoeuvres within the PTW-MDB available. 61 use cases and 650 misuse cases. All data are real signal data. Some of the misuse cases are endurance run data of about 1 to 2 hours duration.
The performance assessment is done in two steps. Firstly, the classifiers are assessed and secondly, the final calculation by the state machine is assessed.

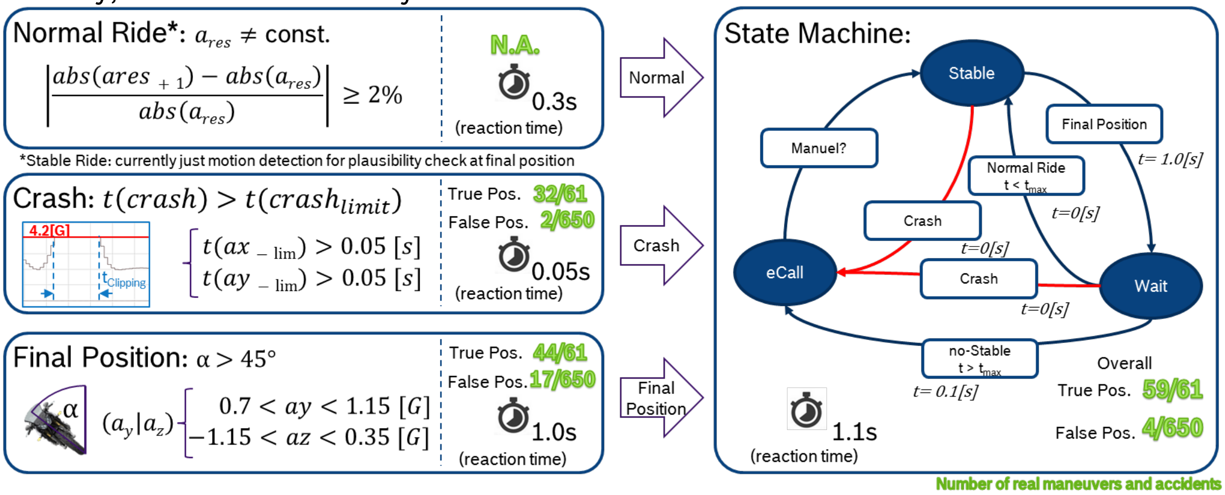

Figure 20: Performance overview of individual algorithm moduls

7.7.1. Normal Ride classification assessment

The Normal Ride classifier is only used as plausibility check within the state machine. Therefore, we did not labelled the data to do a quantitatively performance assessment. The qualitatively assessment shows, that for the current algorithm concept, the classifier as plausibility check is sufficient.

7.7.2. Crash/ collision classification assessment

The Crash classifier is the most crucial part of the algorithm. In case of a positive classification the eCall trigger is directly set. Therefore, this classification has to be as robust as possible in terms of false positive (a non-accident case classified as crash), even if some of the positive cases (crash) are classified as false negatives (an accident case classified as non-crash).

Of the 61 crashes (positives), the current crash classifier detects 32 correctly (true positives). In the remaining 29 crashes, the classifier is not able to classify the crashes correctly (false negative). The false negatives consists mainly of single accidents (low-/ high-sider) and accidents with low speed differences between the collision opponents. Within these accidents, only small acceleration occur and therefore these are not possible to be detected with the chosen concept. Of the 650 misuse manoeuvres, the current crash classifier is not triggered in 648 cases (true negatives). Only in two cases, the classifier interprets the signals wrongly as crashes (false positives). These two manoeuvres are from the MDS database and are rides on cobblestone and over a squared timber. Currently we are unsure if these situations are really a problem or if the data within the MDS database are wrong due to a possible false positioned sensor. We are planning own measurement rides of several misuse manoeuvre of the MDS database to verify the included signals.

Given these results that with our simple concept we already achieve a high robustness. Unfortunately, the true positive classification rate is only moderate. Therefore, we will focus our further development on the improvement of the crash classifier.

7.7.3. Final position classification assessment

The final position classifier is the back up for the crash classifier. As in most accidents the bike finally lies on its side, the classifier can cover most of the use cases. The classification speed is and can be rather slow for this classifier as it is intended to operate during the static status of the bike. Currently the classifier only needs a time and signal window of 1 second for its classification. This time span can be easily increased to improve the robustness in terms of true negatives.

Of the 61 crashes (positives), the current final position classifier detects 44 correctly (true positives). In the remaining 17 crashes, the classifier is not able to classify via the final position correctly a crash (false negative). This is for 16 of these crashes because of missing signal data for the period where the bike comes to a standstill after the crash. Nevertheless, these scenarios are still plausible as the power supply of the sensor could be broken after the crash and therefore no signals are available anymore. Such situations have to be covered by an intelligent eCall system and are not within the scope of the crash detection algorithm development. The remaining not detected case is an accident where a car hits a bike in the rear and the bike is still stuck in it after standstill.
Of the 650 misuse manoeuvres, the current final position classifier is not triggered in 633 cases (true negatives). In 17 manoeuvres, the classifier wrongly detects a lying position of the bike. These manoeuvres are mainly off-road rides, rides on cobblestone or over a square timber. All these cases could be taken care of by increasing the classification time significantly.

Nevertheless, two situations, a toppling bike, remain within our PTW-MDB, which could not be covered by an adjustment of the classification time.

By the assessment of the final position classifier we could prove, that with our concept we already achieved a moderate robustness and a moderate positive classification. Nevertheless, it should be also clear that a simple crash detection based on the final position only is not sufficient and will never cover all possible accident situations. Therefore, a crash detection algorithm has to be extended by further plausibility checks and classifier. We identified the toppling of a bike at standstill as one of the crucial situations for the final position classifier and a situation where OEMs requirements, if an eCall should be triggered or not, will vary. For our further development, we will extend our current concept by the ability to identify the toppling of a bike and make the triggering of an eCall in such a case adjustable.

7.7.4. State machine assessment

Finally, we assessed the performance of the interaction of the classifier within the state machine.

Of the 61 crashes (positives), the current algorithm concept is able to detect 59 correctly (true positives). One crash is not classified due to low acceleration during the impact and due to the upright position at standstill. The other not covered crash is also a crash with low accelerations, but with missing signals at standstill. Again, the second false negative could be avoided by an intelligent eCall system.
Of the 650 misuse manoeuvres, which is equal to 142 hours riding time, the current algorithm concept is not triggered in 646 cases (true negatives) and achieves thereby a high reliability and only four false positives. The crash classifier causes two misfires. The other two are, like mentioned before, a toppling bike at standstill, which cannot be distinguished from an accident at higher speeds by the current concept.

In summary, we conclude that the current crash detection concept achieves a good performance. However, for an eCall product, the algorithm still has to be improved and it have to be taken care of special situations.

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7.7.5. Limitations of algorithm concept

In the sections before, we presented the different modules of our crash detection algorithm and the thereby achieved performance. In the following, we will summarize the general limitations of the current algorithm concept and point out our further development steps.

	Situation:	Critical event:			Accident classification:	
Sensor req.:	Stable Ride	Collision (high)	Collision (low)	High-/ Low-Sider	Critical event & final on side	Critical event & final upright
✓ Basic 3D-acc. (MM5.10 acc. only, ±4.2G)	×	++	×	×	++	+ (Only for high crashes) Focus 2016/Scope of iHeERO
3D-acc. + speed (MM5.10 acc., wheel speed)	+	++	+	+	++	? Currently planned for 2017 @ CR
3D-acc. + turn rate* +CAN* (MM5.10 full, ±4.2G)	++	++	++	++	++	? Finale Crash Detection Algorithm

*Yet, no data available → data has to be collected

++ = robust feasibility; + = feasibility possible; ? = not clarified; × = not possible/not robust

Figure 21: Estimated performance for different sensor settings

7.7.5.1. Situations completely covered by current algorithm concept

The current crash detection algorithm covers all situation where following conditions are fulfilled:

- For all low acceleration crashes, where sensor signals are available for more than one second after reaching the final position and the bike is lying motionlessly on its side.

or

- For all high acceleration crashes, where sensor signals are available during the crash and the shock pulse.

The algorithm concept is robust against all situations where:

- No high and long accelerations occur.

or

- A lying bike is not considered as misuse case.

In general, the chosen concept is not developed for a certain kind of bike and therefore can run on all PTWs. Only the trigger level within the crash classifier has to be reassessed, if it still meets the performance requirements of the specific bike.

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7.7.5.2. Situations coverable by intelligent system design

The current algorithm concept depends on the availability of sensor signals of the crash and post-crash phase. Cases, where the bike is completely destroyed such as that there is no power supply and therefore no CAN signal any more available, could be covered by an intelligent system. Such a system could trigger independent an eCall in case of missing communication via CAN. To increase the robustness, further plausibility checks could be added.

7.7.5.3. Situations not covered by current algorithm concept

Although the presented crash detection algorithm achieves a good performance, there remain some scenarios where the algorithm does not work reliably.
The algorithm is not able to detect following accidents:

- All crashes with low or short high accelerations and an upright final position of the bike.

or

- All crashes where no data are available of the crash and post-crash phase

or

- All crashes with low or short high accelerations, where no signals of the post-crash phase are available

The algorithm concept is not robust against:

- All situation where the bike is lying on its side and these situations are considered as misuse cases.

or

- All non-crash situations where high accelerations for a long duration occur (≥50ms).

7.7.5.4. Further development steps

To overcome the existing limitations of the current algorithm concept, we plan as a first step to add a new physical parameter to the algorithm, the speed of the bike, respectively the wheel speed. By that, we firstly want to adjust the trigger levels of our crash classifier depending on the speed. Secondly, we intend to use the speed information to identify toppling of the bike at standstill. As further step, we try to develop a classifier for low- and high-sider to allow different speed dependent trigger levels for these use cases.

From	Our Reference	Tel	Renningen
CR/AEV1	Florian Mayer	+49(711)811-6332	29 June 2017
CR/AEV1	Henzler Markus	+49(711)811-43433	Report Number
CR/AEV1	Skiera Alexander	+49(711)811-42035	1

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Title: VM-156: Crash Detection for PTW eCall

7.8. I_HeERO

As mentioned within the introduction, the internal crash detection development project was set up because of the running public funded project i_HeERO. Further, some key facts about the project are pointed out.

The i_HeERO Project is a public funded project from the EU, which deals with topics addressing the pan-European eCall. The consortium consists of several governmental organization or ministries, manufacturer, universities and research institutes.

The Powered Two Wheeler cluster (P2W) is a subproject of the overall i-HeERO project and deals with all eCall topics related to powered two-wheeler. The group consists of following members:

ACEM
APRILIA
BMW
BOSCH
CATAPULT
CEIT
ERTICO
HONDA
ICCS
ICOM
ICOOR
ITS NDS
KTM
MINISTRY ITALY
NZI
PIAGGIO
POLIMI
YAMAHA

The main objective of the subproject is to:

1. Derive the PTW Use Cases for an eCall system
2. Derive minimum eCall system requirements for PTWs
3. Derive minimum criteria for triggering an eCall system
4. Define a proposal for a verification standard
5. Define the content of the Minimum Set of Data (MSD) for PTW eCall
6. Analyse the possibility to determine injury severity of PTW accidents

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7. Prepare a homologation process proposal for retrofit solutions

The concept study VM-156 represents CR within the project and has the lead for sub-activity 3.5 “Classification of severity”. The main contributions provided by VM-156 are:

- Define the requirements and architecture of an eCall device for P2W
  → Deriving eCall use-cases out of accident databases
  → Prepare a proposal for verification standard
- Define a reliable triggering mechanism for P2W
  → Using internal P2W riding database to propose reliable triggering concept
- Identify determining factors for accident and injury severity
  → Estimate the potential of P2W eCall
  → Multivariable analysis of accident databases
  → Simulate P2W accidents to link physical parameters (e.g. acceleration.) to injury severity
- Define minimally complex system architecture to improve industry and market uptake
  → Using internal P2W riding database to propose minimum system requirements
- eCall prototype
  → Develop eCall prototype with prototype crash detection algorithm
  → Prove of concept by performing crash test

As the i_HeERO project is running until the end of 2017 and the major results will only be available by then, we refer to the expected official i_HeERO report and to the final report of this project where we will point out major project contributions to the i_HeERO project.

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8. Conclusions and Consequences

During the first project phase, we achieved following results:

- A basic crash detection algorithm was developed from scratch. The presented basic crash detection algorithm already provides a good performance and high robustness. However, it is limited regarding adjustable trigger conditions and is not sensitive to specific situations.
- We set up a maneuver database (PTW-MDB) that contains various crash and normal riding maneuvers of different kind. It is a valuable basis for any further development.
- A patent analysis has been conducted and provides the rail guard for any possible eCall system design.
- A simulation tool chain (BCT) was developed and could be a valuable source to extend the PTW-MDB by missing accident scenarios and thereby increase its representativity. The simulation tool chain is basically able to generate sensor signals of motorcycles, eBikes and dummies on reconstructed accidents, synthetic vehicle-to-vehicle collisions or single accidents. The validation of the vehicle models is still ongoing.

For the remaining project phase, we will focus on following topics:

- The extension of the current algorithm concept. One important aspect will be to increase the adjustability of different trigger levels and classification of accident scenarios. Thereby, we want to increase the performance as well as the robustness of our algorithm. At the same time, we like to be able to meet specific possible requirements from OEMs. A promising candidate for this extension are the usage of wheel speed information.
- To prepare our algorithm for serial development, we will develop a generic verification and validation proposal. Within this task, we will also point out general considerations of topics, which a series development team should take care of.
- The suitability of the simulation tool chain for further development projects will be finally assessed and recommendations derived.
- eCall prototypes will be developed for several bikes. General functionality of these systems will be demonstrated via crash tests in a common I_HeERO event in Renningen.

Enclosures	
Enclosure number	**Title**

BOSCH

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Underlying documents	**please link documents**		
Document number	**Title**	**Date**	**Responsible person**
1	Motorcycle accident simulation and injury severity estimate	28.02.2017	Abdel Nasser Amir (CC-AS/EST4) Mayer Florian (CR/AEV1)

This report invalidates			
Document number	**Title**	**Date**	**Responsible person**