ANIMAL STREET CROSSING BEHAVIOR

AN IN-DEPTH FIELD STUDY FOR THE IDENTIFICATION OF ANIMAL STREET CROSSING BEHAVIOUR USING THE AIMATS-METHODOLOGY

Dr. Christian T. Erbsmehl
Dr. Tom Landgraf
Fraunhofer Institute for Transportation and Infrastructure Systems
Germany

Hitoshi Yuasa
Toyota Motor Europe NV/SA
Belgium

Paper Number 17-0226

ABSTRACT

Based on the police recorded accident data in the German federal state of Saxony (2007-2014), 9.3 % (approx. 85,000) of all accidents involve animals. In 2015, 2,580 accidents involving animals caused injuries in Germany. In order to design ADAS (Advanced Driver Assistance System) in a way that helps to avoid such accidents, it is necessary to understand the animals' behavior. Current methods to observe animal behavior are using vehicle mounted NDS (Naturalistic Driving Study) data. This kind of NDS is expensive considering the number of relevant data sets recorded. This paper delivers the results of a one-year field study that used a new methodology based on in-situ recording units integrated in the infrastructure at critical sites. This way, vast data sets of animal street crossing scenarios can be generated in a quality similar to the one of NDS methods - yet at a relatively low cost.

The definition of the scenarios is based on an in-depth investigation method which was presented at the ESAR conference (Hannover, Germany) in 2016 and is called "AIMATS". An accident data analysis of approx. 85,000 police recorded accidents with wild animal involvement in Germany made it possible to identify locations with a high possibility of accidents involving animals. These locations were observed by means of an infrared camera with a 50Hz frame rate. The recorded camera data allowed a detailed analysis of the movement of all road users. An automated analysis of the recorded results delivers typical and realistic models of the behavior of animals that have encounters with other road users.

For this study, we assumed that the animal behavior at near miss scenarios is the same as their behavior in accident scenarios. This has been confirmed.

This paper describes the results of a large-scale infrastructure-based traffic observation using the AIMATS methods. This method can be used for all traffic scenarios at a relatively low cost rate per scenario.

OBJECTIVE

Based on the police recorded accident data in the German federal state of Saxony (2007-2014), 9.3 % (approx. 85,000) of all accidents involve animals. In 2015, 2,580 accidents involving animals caused injuries in Germany. In order to design ADAS (Advanced Driver Assistance System) in a way that helps to avoid such accidents, it is necessary to understand the animals' behavior. Current methods to observe animal behavior are using vehicle mounted NDS (Naturalistic Driving Study) data. This kind of NDS is expensive considering the number of relevant data sets recorded.

The main objective of this study is to observe normal and critical animal street crossing and vehicle encounters. The results will be used to define typical parameters of animal street crossing behavior and compare them with existing studies. The second objective is to get very robust results by record and to identify **2,500** animal views, **250** animal vehicle encounters and **125** real conflict situations between animals and vehicles. These results have been recorded by using the efficient and economical AIMATS – method by which 64 animal views and six animal car encounters were recorded in eleven days.

In order to meet these set objectives, three major

tasks have to be conducted:

a) Analysis of basic accident dataset and identification of the locations (POI)
b) Building up the measurement units and recording
c) Post processing with trajectory tracking and animal tagging

The following paper describes all individual steps and provides an overview over the overall results and a discussion in the end.

STATE OF THE ART

The technical state of the art was already presented in the first publication of AIMATS in Hannover 2016 in [1]. The state of the art in [1] describes the main disadvantages of vehicle-based recording (NDS) in quantity and quality. Several NDS have been concluded such as the 100-Car study [2] or SHRP2 [3], both conducted in the US, while others (e.g. European UDRIVE [4]) are currently running. The quantity of vehicle-based recording was described in [5] with 350,000 miles and 829 animal vehicle encounters. It also describes the main issues of infrastructure-based recording [6-9].

As a summary it delivers:

"The recording of critical or normal real traffic situations with existing methods has the following disadvantages:
- expensive equipment of the measuring systems (all)
- limitations in recording parameters (NDS)
- accuracy of recorded parameters (NDS)
- flexible recording locations (AIM) "

CHOICE OF MEASUREMENT LOCATION

The selection of all measurement locations is based on the proposition that accidents result from critical situations. Thus, accident black spots are black spots for critical situations as well and therefore are good locations for stationary observation.

To extract the relevant locations from the police recorded accident data a base set of all accident with participation of wild animals (encoded by the police or classified from accident description) in Saxony and south of Brandenburg has been defined. This dataset covers the years from 2010 to 2015 and consists of over 1 million accidents with wild animals.

By clustering the data by location, accident black spots can be ranked and measuring locations can be identified. The clustering is performed at two levels:

1. pre-selection using 2d density mapping and
2. distance-based clustering on selected accidents.

At the first level, it is necessary to make a pre-selection of relevant accidents, due to the fact that a classical distance-based clustering is very extensive for this amount of data. At the second level, an agglomerative, distance-based clustering is used with a maximum cluster diameter of 150 meter. To tackle the problem of possible changes over time, the data is additionally weighted by the accident year. New accidents gain a weight of 100% and the oldest accidents (year 2010) gain only 20%. This leads to a cumulated weighted number of accidents (short weight) for each cluster. All clusters are ranked by this weight.

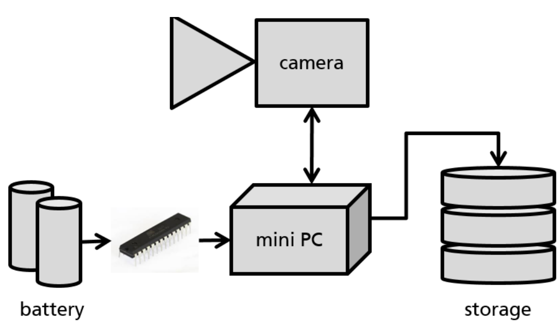
The final measurement locations (as seen in **Figure 1**) are part of the top 50 locations where the researchers have obtained the permission of local authorities.

Figure 1: Realized Measurement Locations

USED EQUIPMENT

The basic approach of the measurement equipment is similar the equipment used in [1].

Figure 2: Basic scheme of measurement equipment [1]



Since wild animal vehicle encounters mostly happen in dusk, dawn or night and mostly in forests, a far range infrared camera system was chosen. This allows the measurement system to operate independent from light conditions. The far range infrared systems enables the system to also record native absolute anonymous data.

Figure 3: Example of an infrared picture (no faces)

The following additional requirements have to be taken into account.

- Waterproofness of all components
- Independent power supply on the ground
- Computer and storage as high as possible (to prevent theft)
- Camouflaged camera system (birdhouse-style)

The following pictures give an impression of the system components:

Figure 4: Birdhouse-Style camera, and processing box

Figure 5: Interior of the processing box

Figure 6: Camouflaged power supply on the ground

All components allow a site-independent and fast installment of the measurement system.

MEASUREMENT PERIOD

The measurement process was divided in three different phases for each location:

- Installing process
- Measuring process
- De-installing process

Install Process

During the installation process, a detailed sketch of the street in front of the camera has to be produced. Once the sketch is ready, reference points for the following automated image processing process have to be specified and measured. Lighted grave candles are a very convenient way to identify reference positions.

Figure 7: reference positions with grave candles

The last step during the installment process is a reference drive through the location at a constant speed to adjust the later used algorithms.

Measurement Process

After the installation the measurement runs round about three to four days and 25fps with 24h recording enabled. After this time a student investigation team changes the power supply and the HDDs with the stored data. During the measurement location service, the functionality and all recording parameters of the camera system were examined as well. Later, the infrared video material was copied to recording servers.

De-installment Process

After two weeks, the measurement systems were de-installed. Before the complete de-installation, a second reference measurement was conducted to ensure that the observed area was still the same as at the beginning. After the de-installment process the equipment was cleaned and conditioned for the next operation.

During the measurement period, 31 different locations distributed all over Saxony (Germany) could be measured by using 5 measurement systems. The mean measuring time per location was round about 14 days a season. The first measuring period was in spring 2016 and the second period was in autumn 2016. Repeating the measurements at all locations gives the possibility to eliminate season effects.

This makes up a total amount of **14,590** hours of infrared video material. The framerate for the recording was **25fps**. The overall data volume was **164 TB**.

Some examples of the measurement period are given in the following.

The first picture shows a large group of 24 boars. This gives a first impression of the different scenarios that are recordable on streets.

Figure 8: Large group of wild boars

The next picture shows a roe on the road and a full braking car in reaction to this obstacle

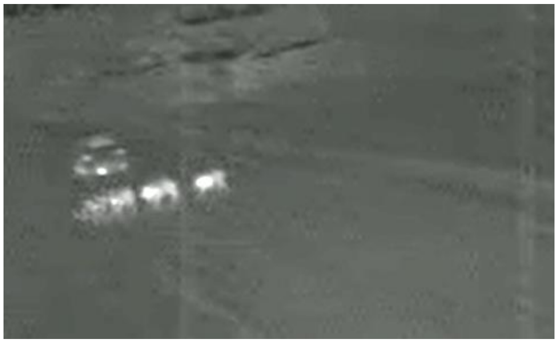
Figure 9: Roe and full braking car

The following picture shows three unimpressed roes and one deer shortly before a critical situation with the approaching car.

Figure 10: Roes and deer before a critical situation

The next picture has a very bad quality because of heavy rain that night. It shows a group of four wild boars which are crossing the street in front of a car.

Figure 11: Group of wild boars in front of a car



The following picture shows the second of two roes crossing the road shortly before a very close situation with the car.

Figure 12: crossing roe before a car

The next picture shows two tenacious wild boars following the leading boar and a car which brakes to zero km/h.

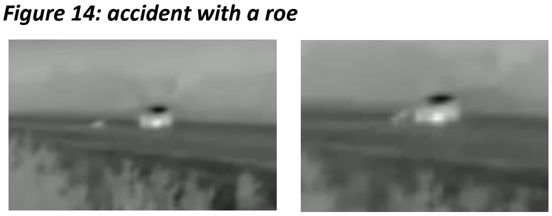
Figure 13: wild boars and hard braking car

These are some examples from the whole dataset of 14,590 hours. The total number of critical scenarios will be given in the chapter results.

The AIMATS – approach assumed that critical situations of a pre-analyzed accident scenario happen very often and are recordable, but that it is nearly impossible to record an accident. This statement has to be revised. During the study, three real accidents (one with three collisions) between vehicles and animals could be recorded and are shown in the following.

The first recorded accident was an accident with a roe coming from the left. The bad quality of the pictures is caused by the high zoom level.

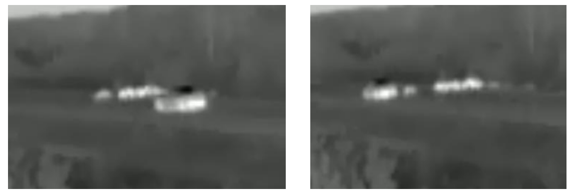
Figure 14: accident with a roe



The second very interesting accident is an accident with the leading roe of a huge wild boar group in a high speed range. The colliding car has an initial speed of 130 km/h (100 km/h are allowed) and brakes until the collision at 60 km/h. After the collision the car evades and does not come back

There are four further cars, which crash into the dead wild boar lying on the street.

Figure 15: Accident with the leading wild boar of a huge group



The last identified accident is an accident with a big fox or a badger that comes from the left. The car is trying to evade to the right but the evasion could not prevent the accident.

Figure 16: Accident with a badger

The measured accidents prove the truth of the AIMATS – approach. AIMATS is not only able to measure critical situations, it is even able to record accidents if the locations are identified well.

IMAGE PROCESSING, TRACKING AND CLASSIFICATION

The analysis of the recorded temperature videos is splitted into three phases. First, an image segmentation is performed. This means all non-static objects are located and projected to the base point (on ground level) in world coordinates. Second, all object points are tracked over time and transferred into trajectories of objects. As a third and last step, features are calculated for all trajectories. Based on these features, a classification is performed.

Image Segmentation

The image segmentation uses a background estimation algorithm (based on a Kalman Filter). With respect of the special properties of an infrared camera, an additional temperature stabilization is necessary to reduce the shutter effect, which produces big step-like changes in absolute temperature values every time the camera recalibrates on its shutter. The bounding box is calculated for all detected objects and the base point is estimated. The base points of all detected objects including temperature features (e.g. mean/maximum temperature of the object) and the corresponding timestamp are the result of the first phase (segmentation).

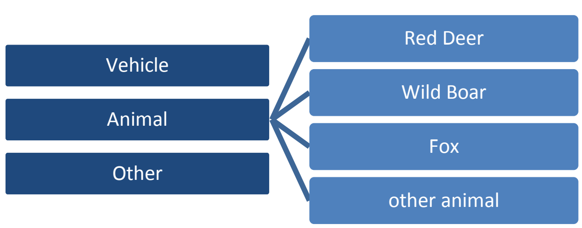
Tracking

During the tracking phase, all object points should be assigned to trajectories. This is realized with a Kalman-Filter based tracker that estimates a smoothed trajectory and allows the prediction. If an object location is close to the predicted trajectory position, the object is assigned to the trajectory. Otherwise, it starts a new trajectory. In a first processing step, only the special distance is used. In a second step, the resulting velocity for the trajectory is checked and the algorithm allows to separate trajectories if the velocity plot is not plausible. The smoothing effect of the Kalman Filter also compensates the "fuzzy" appearance of the object position, due to discretization effects esp. for distances between camera and objects above 150 m. The result of the second phase are object trajectories with smoothed position plots. It is important to mention that one trajectories does not necessarily represent one object moving through the scene. One object could create multiple trajectories, e.g. due to occlusions.

Classification

The third phase implemented the object classification. The classification is based on the class definition as shown in Figure 17.

Figure 17: class definition for the classification of objects (excerpt)



The classification is conducted with a Maximum Likelihood Estimation (MLE). For each class a multivariate Gaussian distribution is derived from a set of training data. This training data set consists of more than 10,000 manually annotated objects of the named classes.

The classification achieves an accuracy of 87 % for animal detection and over 95 % for vehicle detection (according to a leave-one-out cross validation). As result of the third phase, all trajectories carry an object class. This allows the evaluation of all *vehicle* to *animal* encounters. Using a time-based criterion, an animal to vehicle encounter is defined as:

$$t_x = \check{d}_{vehicle2animal} / \bar{v}_{vehicle}, \qquad \text{(Equation 1)}$$

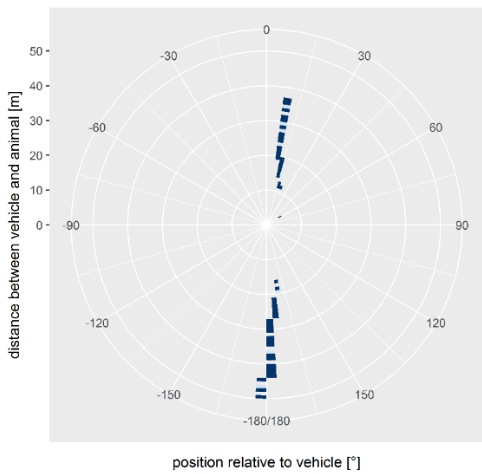
where $\check{d}_{vehicle2animal}$ is minimal Euclidian distance between the animal and vehicle trajectory, $\bar{v}_{vehicle}$ the average velocity of the vehicle and t_x.time-based criterion for criticality. This criterion allows the separation into the groups: **encounters** ($t_x < 3\,\mathrm{s}$) and critical encounters ($t_x < 0.5\,\mathrm{s}$) (called **criticals** in the following).

To concentrate these high numbers of trajectories into a descriptive figure, all vehicle and animal trajectories are transformed into a coordinate system relative to the vehicle. Thereby, the angle is 0° for driving direction and positive to the right (in driving direction). By generating a distance angle histogram, the trajectories of a vehicle passing an animal transforms into the trace such as shown in the image in Figure 18.

RESULTS

The analysis of the recorded video sequences of all measurement locations leads to 48 thousand **encounters** and 15 thousand **criticals** (based on trajectories).

Figure 18: vehicle passing an animal transforms into a trace in distance-angle-histogram (relative to vehicle)



Location of the Animals

Figure 20 shows the distance-angle-histogram for all encounters. It is obvious that most encounters happen in front of the car. Within a -15° to 15° section the left to right ratio is 40% to 60%. This means a slightly higher probability for encounters from the right.

Figure 20: distance-angle-histogram for all encounters

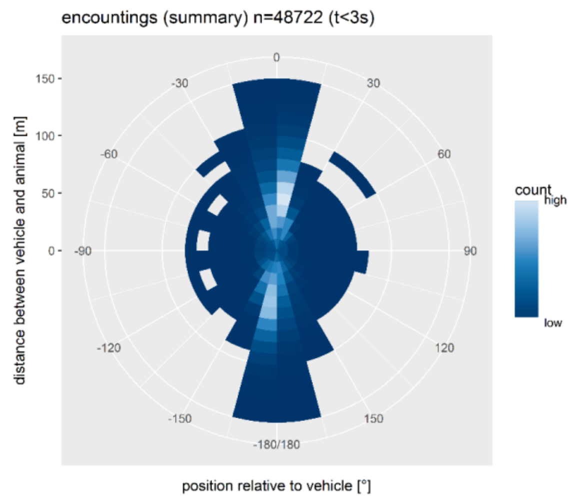
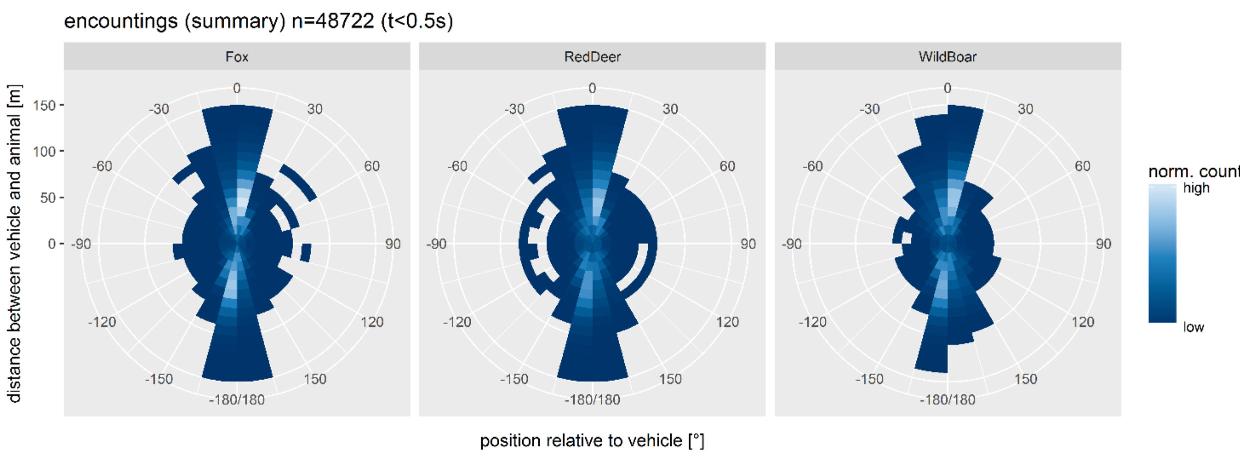


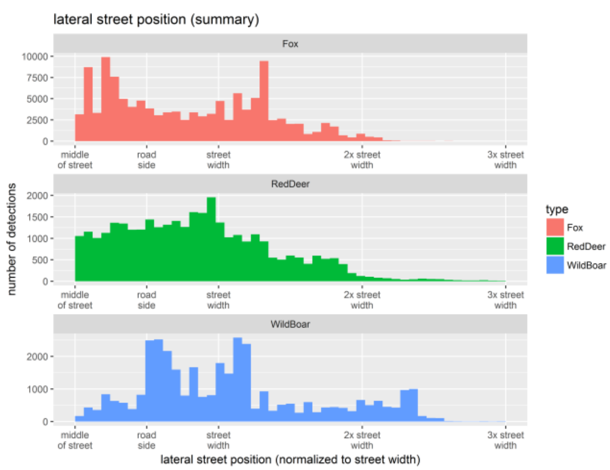
Figure 19 shows that this characteristic is similar for the animals monitored in this study: red deers, wild boars and foxes.

Figure 19: distance-angle-histogram for all encounters by animal



The differences between the animals become visible in Figure 21. The figure shows the histogram of the animal's lateral position (normalized distance from the middle of the street). The distributions shows that foxes are common on the street. This corresponds with the impression received from reviewing the videos manually. The foxes follow the street on lookout for food and hide out when a vehicles approaches. Wild boars spend a lot of time next to the street (roadside ditch). The manual review reveals that they look for food e.g. from the oak or beech trees next to the street. For red deers, the observation shows that most of them just pass the spotted area. This corresponds with the more even distribution in Figure 21.

Figure 21: lateral position of the animals (relative to the street)



It is remarkable that the wild boar appear in groups whereas foxes and red deers are typically roaming their environment on their own.

Initial Spotting Distance

The spotting distance could not be evaluated from the data, because the driver is not monitored directly. So the initial spotting distance is approximated by the initial distance between animal and vehicle. This distance is the Euclidian distance of the first trajectory points of an encounter.

Table **1** shows the average values for the different animals.

Table 1 average initial (spotting) distance

Animal	**Avg. Initial Distance**
Red Deer	29.6 m
Wild Boar	31.6 m
Foxes	30.3 m

Speed of Vehicles

The vehicle speed is important for the design of assistance functions as well as passive safety. The average speed of all vehicles (no encounters) and all locations is 85.5 km/h. Table 2 shows the average of speed of vehicles in encounter situations. The speed of the vehicles are only approx. 5 km/h lower compared to non-encounter situations. The average speeds are higher than expected from the comparative study. The reason for this might be the fact that this study surveils larger streets.

Table 2 average speed of vehicles in encounter situations

Animal	**Avg. Vehicle Speed**
Red Deer	78.9 km/h
Wild Boar	80.2 km/h
Foxes	79.1 km/h

Speed of Animals

Beside the speed of the vehicles, the speed of the animals allows several discussion on animal reactions.

Table **3** shows the average speed of animals subdivided by animal, situation (non-encounter, encounter and critical) as well as the location of the animal (on/off street). Red deers have the highest average speed of 9.8 km/h (overall average), compared to foxes (2.6 km/h) and wild boars (2.2 km/h). All animals move fast on streets. For wild boars and foxes, the average speed also increases when the criticality rises - as expected. Remarkable is the behavior of red deers. They show a decreasing average speed off street, but in critical on-street situation, the average is lower than the other on-street values. This could be a reaction caused by dazzle.

Table 3 average speed of animals by situation and location

situation	location	average speed in km/h		
		red deer	wild boar	fox
non-encounter	off street	9.6	1.1	1.7
	on street	10.5	1.9	2.1
encounter	off street	8.0	1.2	1.7
	on street	10.8	2.6	2.4
critical	off street	7.6	1.4	2.0
	on street	10.1	2.6	3.0

Estimated Time To Collision

The time to collision is approximated by the quotient of the distance between animal and vehicle and the average speed of the vehicle. A real TTC could only be calculated for crossing trajectories of animals and vehicles. This requires a prediction of the trajectories. The approximation uses the simple model, the vehicle moves on constant speed. The speed and direction of the animal are neglected here, due to the fact that the reaction of the animal is hard to predict. Table 4 shows the estimated TTCs (median) for the different animals.

Table 4 median TTC by animal

Animal	Median TTC
Red Deer	1.3 s
Wild Boar	1.4 s
Foxes	1.3 s

Distance When Driver Applies Break

The distance when the driver applies the break, cannot be derived directly from the trajectories, because this moment is often not visible due to the limited field of view. As an approximation, the average initial distance of all breaking drivers is calculated. The distinction between breaking and non-breaking driver is based on the average deceleration of the vehicle, if the deceleration of the vehicle exceeds 2 m/s². Table 5 shows the estimated average distance when the driver applies the brake.

Table 5 average distance when driver applies brake

Animal	Avg. Distance Braking
Red Deer	33.1 m
Wild Boar	34.3 m
Foxes	33.3 m

Impact Location

Figure 22 shows the distance-angle histogram for criticals (up to 5 m distance) to get an impression of possible impact locations. For red deers and foxes, a preference to the front is visible. For wild boars, clusters arise in front as well as on the side. The monitored accidents fit into these propositions. The roe impacts into the front of the vehicle. At the first wild boar accident, the animal impacts into the side. In the second accident in the following traffic, the impact location is in front of the car.

Figure 22: estimation of impact location by animals

In comparison to the state of the art [10] all results are arranged in Table 6.

Table 6 summary of results (comparison to state of the art)

Parameter	Deer	Wild Boar	Fox
Animal Location	left / right	left / right	left / right
No. of Animals	single	groups	single
Lighting Conditions	dark, sunrise/ sunset	dark, sr/ss	dark, sr/ss
Initial Distance	29.6 m	31.6 m	30.3 m
Vehicle Speed (at encounter)	78.9 kph	80.2 kph	79.1 kph
Animal Speed (at encounter)	2.7 m/s	0.6 m/s	0.7 m/s
Estimated TTC	1.4 s	1.5 s	1.5 s
Distance when driver applied brake	33.1 m	34.3 m	33.3 m
Impact Location	front	front/side	front

DISCUSSION AND OUTLOOK

Using the AIMATS- scheme was the first time to record scenarios in this scale. All results confirm the AIMATS assumptions and are even expanded by recordings of real traffic accidents. This was unexpected. Due to vast amount of recorded data, the results are reliable and robust. Furthermore the main results of two other studies to describe animal- vehicle encounters (SHRP2 and CSRC) [3] [10] could be confirmed.
The summarized final results match in general the results which were given by the SAE-Paper [10] of CSRC and SHRP2.

The most significant differences were in following three categories:

- **Vehicle speed at encounter**
- **Distance to animal when the driver applies the brakes**
- **Estimated TTC**

All three points will be discussed in the following.

The ***Vehicle speed at encounter*** in this study is round about 79 km/h. The SHRP2 data gives 64 km/h as an average and the CSRC Data gives 53 km/h. The higher speeds depend mainly on the measurement place and the allowed speeds. This study was implemented on rural main roads, which gives all drivers the possibility to drive up to, or, in many cases, above the speed limit of 80-100 km/h.

The ***Distance to animal*** when the driver applies the brakes is in the comparable basic studies between 10m and 30m. In this study, an average distance of 33m was calculated. In fact it is no big difference but should be discussed as well. The deceleration of the car is estimated from the trajectory and the 25 fps time steps. The used algorithm is not able to get a reaction time or that exact measures of a NDS- measurement system. One more reason for a larger distance could be the higher speed at the location that has been discussed above.

The ***Estimated TTC*** in this study is much smaller than in both other studies. The CSRC Study gives 5.5sec and the SHRP2 data gives 1.9sec. This study gives an average of 1.5sec. Reasons for the big difference is again the much higher traveling speed. One important finding related to this short TTC is that warning systems will have no realistic chance to inform the driver in time. TME and Fraunhofer IVI have launched a driving simulator study for a different topic in 2016. In the results, we could find a realistic reaction time for a distracted driver to apply the brakes after optical and acoustical warning of 1.5 second (in mean of 75% of all drivers). For focused drivers the mean time is 1.0 seconds (75 % of all drivers).

The efficient and economic AIMATS- method can be used to record a huge set of critical scenarios moreover some single accident events could be investigated.

Nevertheless, further improvements have to be developed in future studies.
The accuracy of the tracking algorithm including the handling of hidden parts of participants has to be optimized. This can be done by using a higher resolution in the infrared camera, other lenses, more cameras or by the improvement of the algorithms. New hardware components have to be defined and tested.
This can be done by further developing the image processing and tracking algorithms which are

based on the developments presented in this paper. These algorithms should be optimized for the detection of animals, cars, bicycles and pedestrians. To meet the demands of the more complex traffic at intersections, the algorithms have to be extended and optimized to intersections.

REFERENCES

[1] Erbsmehl, Lubbe, Yuasa, Landgraf, Ferson, Urban: "Analysis and Investigation Method for All Traffic Scenarios (AIMATS)"; ESAR 2016, Hannover, Germany

[2] Dingus, T. A., Klauer, S.G., Neale, V. L., Petersen, A., Lee, S. E., Sudweeks, J., Perez, M. A., Hankey, J., Ramsey, D., Gupta, S., Bucher, C., Doerzaph, Z. R., and Jermeland, J. (2006). The 100-car naturalistic driving study, Phase II – results of the 100-car field experiment (Contract No. DTNH22-00-C-07007). Washington, DC: National Highway Traffic Safety Administration

[3] http://www.shrp2nds.us/

[4] http://www.udrive.eu/

[5] Alden, A.S., Mayer, B., McGoven, P., Sherony, R., Takahashi, H. (2016). Animal-Vehicle Encounter Naturalistic Driving Data Collection and Photogrammetric Analysis. Presented at SAE World Congress, April 12-14, 2016.

[6] http://www.tft.lth.se/en/research/video-analysis/

[7] Ardö, H. **MULTI**-TARGET TRACKING USING ON-LINE VITERBI OPTIMISATION AND STOCHASTIC MODELLING. Dissertation Lund University 2009. Available at: http://www.maths.lth.se/matematiklth/personal/ardo/thesis/

[8] Varhélyi, A. Driver's speed behaviour at a zebra crossing: a case study. Accident Analysis and Prevention Volume 30, Issue 6, November 1998, Pages 731–743

[9] http://www.dlr.de/ts/desktopdefault.aspx/tabid-6422/#gallery/25304

[10] Rini Sherony: "Deer Radar Scanning and Naturalistic Driving Data Collection / Analysis"; SAE 2015 Active Safety Systems Symposium, Plymouth, USA