Car-Forensics 4.0

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Forensic Report
Accident Uber-Volvo 18.03.2018

(Extract from Research Project Car-Forensics)

www.car-forensics.de

Research Project Car-Forensics

Digital Forensics, IT-Security and Privacy in the context of,
Connected Cars and Functional- and Road-Safety

DigiFor Inside 04-2018

Forensic Report Accident Uber-Volvo 18.03.2018 in Tempe, Arizona (USA)

Impress

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https://www.KaeferLive.de and https://www.car-forensics.de

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Corrected version from 06. August 2018: As it turned out later, the date 19/03/2018 extracted from the video published by the police is wrong. The accident occurred according to the later submitted police report on 18/03/2018 at 22:00 local time.

1 Content

1.1 DigiFor Inside

What is DigiFor Inside? DigiFor is the abbreviation for the term "digital forensics", an area of IT specializing in the analysis and detection of incidents and misuse of computers in the context of crime and civil litigation. DigiFor Inside is a series of specialist articles and publications in which the author Thomas Käfer talks about IT security issues and reveals concepts of intervention and measures for their detection or defense.

For more articles, see https://www.car-forensics.de

1.2 About Car-Forensics

The increasing networking of vehicles with each other (Car2Car), with smartphones (Car2Phone) and central infrastructures (Car2Infrastructure) as well as optional or future obligatory vehicle-to-implement extensions - such as accident data recorders and e.g. the system "eCall" - are far from unexplored under IT security aspects and data protection considerations. The storage and exchange of vehicle and movement data arouse desire in the police and judiciary (for example in the context of traffic monitoring and traffic offenses, law enforcement and accident reconstruction), insurance companies and service providers, but also with criminals.

The research work Car-Forensics is intended to provide a first overview of what is technically already possible and conceivable in the field of digital forensic evaluation of the IT systems installed in the vehicle or externally coupled with them. In this context, it will be examined which legal bases are currently available and applicable and where there is a need for regulation by the legislator in the near future. For this purpose, in the theoretical part of the paper amongst other things comply with applicable data protection and data security standards, regulations and standards in both legal and technical aspects.

In the practical part of the research work, it was researched and exemplarily examined, which interfaces the different systems possess, which can be addressed or evaluated forensically. In doing so, both openly communicated standards and accesses were accessed as well as e.g. using hacking and analysis tools with the help of reverse engineering methods, a data analysis or manipulation tries. Using methods from digital forensics and typical attackers, examples were examined of the extent to which technical and organizational safeguards can be circumvented in order to eliminate access backlogs or which data is actually transferred and stored.

Objectives of the research are thus, inter alia, to make statements on data protection and data security from the perspective of users (users), to examine the forensic opportunities and rights for experts and investigators and a Code of Conduct for Car2Car, Car2Infrastructure and Car2Person communication define.

1.3 About this report

The present article deals with the forensic evaluation of the accident of 19/03/2018, in which a fully automated driving Volvo of the transport service provider Uber in Tempe, Arizona collided with a pedestrian, who subsequently died of her injuries.

It is remarkable, according to the author, how much can be read from the publicly available sources and the video published by the police in Tempe with further metadata of the vehicle and thus with careful and correct interpretation of the material so far largely superficial to false reporting in the media.

For further causal research, what has happened within the vehicle system, of course, one must have access to the car and the information stored therein. The author had (so far) for obvious reasons not.

The article is to be seen as a supplement to the previous editions of the research report Car-Forensics and is part of the current fourth edition of April 2018.

1.4 About the author

Dipl.-Ing. Thomas Käfer, M.Sc. has been working independently in IT since 1990 with his IT system house Käfer EDV Systeme GmbH. The field of activity of the company Käfer EDV Systeme GmbH includes consulting services in the field of IT security including penetration testing and others in the automotive industry. Thomas Käfer has been working since 2002 as an expert for systems and applications of information processing (publicly appointed since 2006), as an IT consultant, specialist author and deals mainly with issues of IT security, data protection and the field of digital forensics. Honorary offices as a commercial judge at the Aachen Regional Court and as a member of the General Assembly of the IHK Aachen complete his activities. In 2015, he successfully completed the extra-occupational master's program "Digital Forensics" at the Albstadt-Sigmaringen University of Applied Sciences in cooperation with the LMU Munich and the FAU Erlangen, and in this context created a comprehensive research work on the subject of digital motor vehicle forensics. Thomas Käfer regularly deals with issues of IT security and the forensic evaluation of modern vehicles and IT systems that are linked to them. He is a speaker at IT security and privacy events and holds trainings and workshops for the automotive industry, suppliers, government agencies and associations.

2 Forensics report of the accident of 18.03.2018

On 18/03/2018, a fully automated Volvo-type vehicle XC90 SUV crashed during test drives of the car service provider Uber in Tempe, Arizona (USA). A 49-year-old female pedestrian was hit by the vehicle and killed while crossing the multi-lane road.

Shortly after the accident, Tempe police released a video showing both the front and rear view of the car before and at the time of the accident. Based on this video, which was picked up and disseminated by a variety of news channels, and the initial information from the police, a number of allegations and guesses have been made regarding the course of the accident and the question of guilt, which can be seen on closer examination and evaluation of the original video footage superficial, misleading and sometimes wrong. With regard to the acceptance of fully automated or autonomous vehicles, the first accident of such a fatal vehicle for an uninvolved pedestrian is a major setback for the entire Vision Zero project. Especially in relation to the still valid advertising statement of Volvo from the year 2010 that from 2020 no one is seriously injured or even killed in a then new Volvo vehicle, the accident shows that how far we are still away from this target. Therefore, it is important to carefully analyse and clarify this incident. Furthermore, regardless of human tragedy, the case is well suited to highlighting the possibilities and limitations of investigating such an accident and to making hasty, entirely incorrect conclusions based on incomplete or incorrect information.

2.1 Claims and press releases

The following statements were apparently first spread based on the first statements of the local police in the US and the video material:

1. The injured pedestrian (who has pushed her bike over the road) has suddenly come out of the shadows[1].
2. The vehicle should have been in fully automated mode at the equivalent of 64 km / h (40 mph) instead of the allowed at the accident 56.3 km / h (35 mph)[2].
3. The vehicle should have neither significantly delayed nor made an evasive movement [3].
4. The driver for monitoring on board the vehicle should not have intervened[4].
5. The accident would have been unavoidable even by a human driver[5].
6. Police from Tempe, Arizona (Sylvia Moir) said that it looked like Uber was not to blame for the accident and charges against the driver were not ruled out[6].
7. The vehicle was equipped with RADAR sensors, cameras and a LIDAR system.[7]
8. On 27/03/2018, Uber was withdrawn from the permit for further tests with autonomous vehicles until further notice [8].
9. Uber equipped the vehicle with its own hardware or software and switched off the standard collision system from Volvo [9].

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[1] various sources, exemplary (Forbes, n.d.)
[2] various sources, exemplary (WDR, 2018)
[3] various sources, exemplary (Newsweek, 2018)
[4] various sources, exemplary (Newsweek, 2018)
[5] various sources, exemplary (Autobild, 2018)
[6] various sources, exemplary (Network, 2018)
[7] various sources, exemplary (Bloomberg, 2018)
[8] various sources, exemplary (Spiegel, 2018)
[9] various sources, exemplary (Coppola & King, 2018)

Quelle: National Transportation Safety Board

Illustration 1: Accident vehicle in the investigation by police and specialists

2.2 Own investigations and evaluations

As expected, the partly lurid and contradictory media coverage of the accident has aroused the interest of the author Thomas Käfer and led him to make his own evaluations of publicly available sources.

It is particularly noticeable after a first sighting of the video material freely available on the Internet about the crash that the picture of the front camera is very dark and the pedestrian actually seems to emerge from the shadow just before the collision. This initially nourishes the thesis that the accident would have been unavoidable even for a human driver:

Illustration 2: Cutout Dashcam video (source YouTube - resolution 636 x 360 px)

Attempts to whitewash the video through post-processing filters fail because of the poor quality of the source material. In all sources accessible on the Internet, the additional information is also pixelated at the edge of the picture. The author has therefore contacted the police in Tempe, Arizona and asked to be sent the original images from the press release. In fact, one day after his request he received a better quality version with a resolution of 848 x 480 and 25 fps, which also contained the additional information in plain text without pixels (front camera):

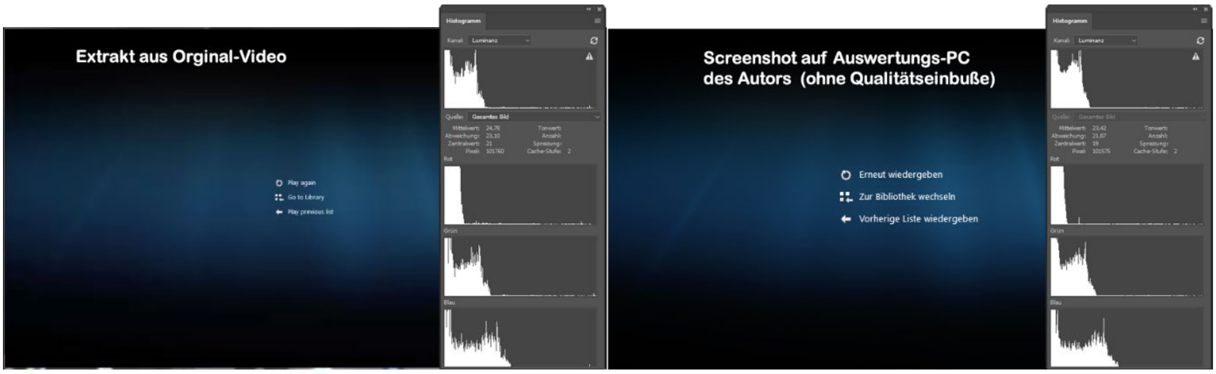
The videos accompanying this forensic report in German and English are available at www.car-forensics.de . Link: https://www.kaeferlive.de/index.php/medien-forensik/videos-and-webcasts

Illustration 3: Cutout Dashcam video (source police Tempe - resolution 848 x 480 px)

Unlike the shortened video on YouTube, the video starts sooner (just before the bridge is undercut), so important details become visible for further analysis.

First, it is striking that the interface between the outside and inside view and at the end of the video briefly, the background image of the Windows Media Player is visible. If one compares its quality (and brightness) with that of a screenshot on the author's evaluation PC after playing the original video, one recognizes that the latter is qualitatively clearer and a little brighter. This leads to the conclusion that the police has not evaluated the original video from the vehicle or distributed, but this was recorded and cut from a PC presumably using a screen recorder. In the process and the subsequent export of the edited video material, it seems that there has been a loss of quality. It is even conceivable that the original video was filmed with a video camera or a smartphone. That would then be an extremely negligent and unprofessional procedure with regard to the evaluation.

Extremely questionable is why not the digital output file was used in the highest possible resolution. One could assume that the video was deliberately played on a PC and this brightness or quality reductions were deliberately or at least negligently accepted.



Mittelwert: 24,78
Abweichung: 23,10
Zentralwert: 21
Pixel: 101760
Tonwert:
Anzahl:
Spreizung:
Cache-Stufe: 2

Mittelwert: 23,42
Abweichung: 21,87
Zentralwert: 19
Pixel: 101575
Tonwert:
Anzahl:
Spreizung:
Cache-Stufe: 2

Illustration 4: Compare reduced quality police video to possible resolution / brightness

The histograms show the slightly higher dynamics of the screenshot (right) with less noise compared to the video provided by the police (left).[10].

Should the video still depict the real lighting conditions 1:1, this would in turn mean that the visibility has reached only to the limit of the driving light (here dipped beam). Since you can only drive so fast that you can stop the vehicle at any time within sight, this would mean that you would have to drive much slower in these light conditions. The visibility can be measured on the median strip in the video and the comparison with Google Earth to about 25 m. This in turn leads to a maximum permissible speed of 45 km / h (equivalent to 28 mph) for conventional assumptions (1 s reaction time, 6 m / s 2 deceleration on dry asphalt)[11]).

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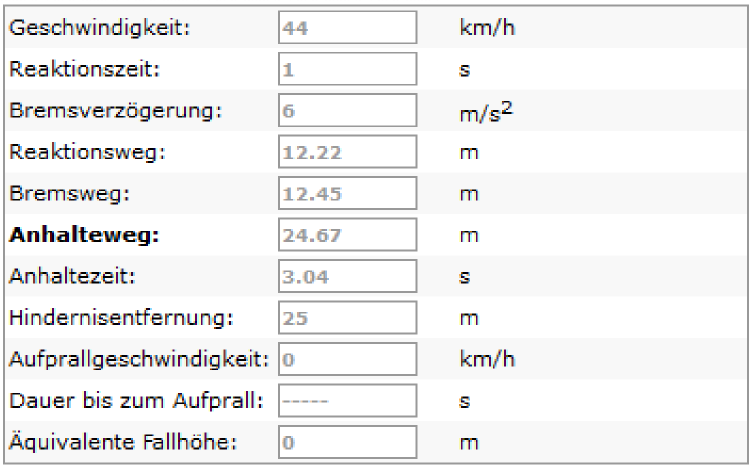
[10] Note: The evaluation of the images was done with Photoshop in single image mode without any further change of the source material. The differences are not as clearly visible in a printed report as on the screen.

[11] Conversion 1 mph = 1,60934 km/h



Geschwindigkeit:	44	km/h
Reaktionszeit:	1	s
Bremsverzögerung:	6	m/s²
Reaktionsweg:	12.22	m
Bremsweg:	12.45	m
Anhalteweg:	24.67	m
Anhaltezeit:	3.04	s
Hindernisentfernung:	25	m
Aufprallgeschwindigkeit:	0	km/h
Dauer bis zum Aufprall:	-----	s
Äquivalente Fallhöhe:	0	m

Illustration 5: Calculation stopping distance at sight 25m (German only)[12]

From the metadata contained in the image border one can read off further information and further process it for the evaluation. Thus, the time stamp shows that the accident took place on 18/03/2018 at 04:58:50 UTC (corresponds to 00:58:58 local time) in the geographic coordinates LAT 3326.1456 LON 11156.5195 at a speed of 40 mph[13]:

Illustration 6: Picture from the police video immediately after the impact

The values X, Y and Z presumably indicate the acceleration in the longitudinal and transverse axis or vertically downward (gravitational acceleration) and the value "sum" is used to determine a vector sum (mathematical magnitude) for the resulting acceleration. At 8.25 m / s² this value is significantly higher than the normal values during a journey and indicates the impact.

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[12] Source: http://www.kfz-handwerk.de/bremsweg.php

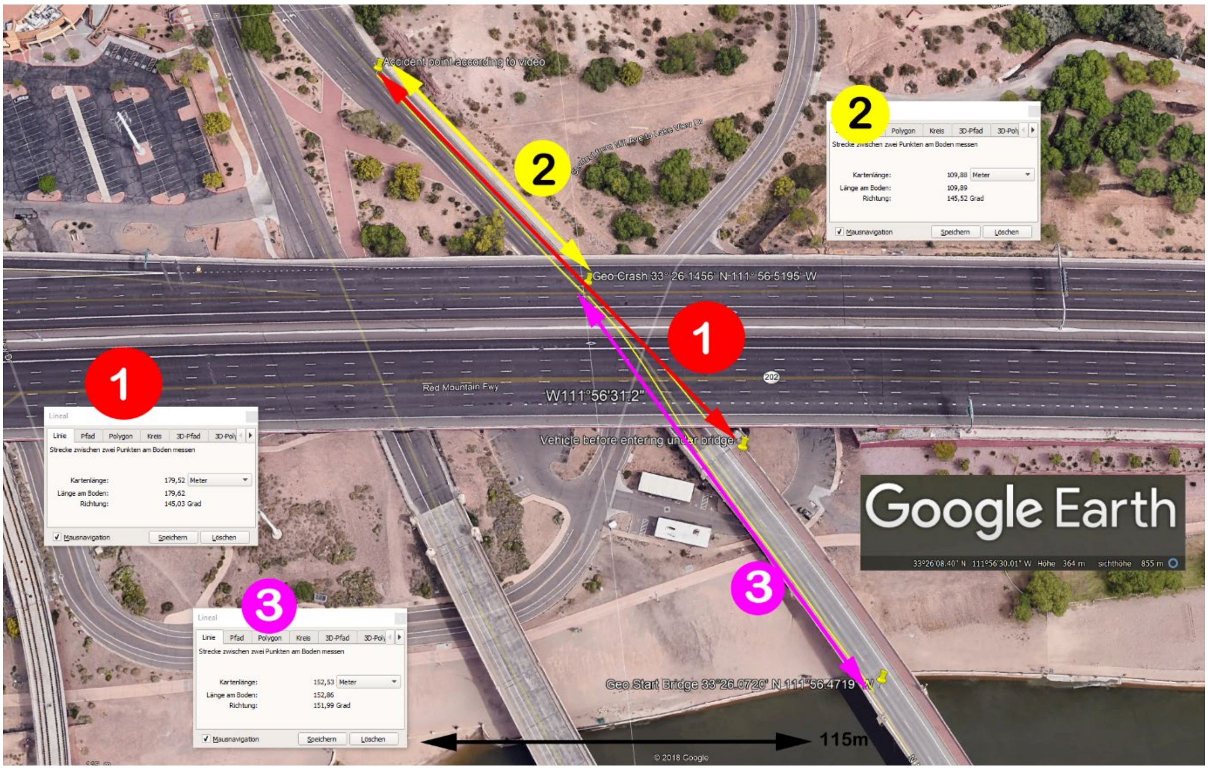
[13] Corrected version from 06. August 2018: As it turned out later, the date 19/03/2018 extracted from the video published by the police is wrong. The accident occurred according to the later submitted police report on 18/03/2018 at 22:00 local time.

When interpreting the geo-coordinates that evidently originate from an internal GPS receiver in the vehicle, one must be very careful not to accidentally apply the wrong measurement system, as no unit notation is given here.

From the approximate location of the press coverage, it is known that the accident happened in Tempe, Arizona near the Marquee Theatres.

If one interprets the values as degrees, minutes, seconds and in this case the seconds as a decimal value, this leads to 33 ° 26 '14.56' 'N 111 ° 56' 51.95 '' W. These values lie about 500 m away from the actual accident location. This is significantly more than the usual error of the GPS signal of less than 15 m.

However, if you interpret the values as degrees and minutes and the minutes as a decimal value with decimal places, this leads to 33 ° 26.1456 'N 111 ° 56.5195' W. This value is plausible because it lies on the vehicle's travel path. However, the distance to the actual accident point at this time is approx. 108 m.



2
Strecke zwischen zwei Punkten am Boden messen
Kartenlänge: 109,88 Meter
Länge am Boden: 109,89
Richtung: 145,52 Grad

1
Strecke zwischen zwei Punkten am Boden messen
Kartenlänge: 179,52 Meter
Länge am Boden: 179,62
Richtung: 145,03 Grad

3
Strecke zwischen zwei Punkten am Boden messen
Kartenlänge: 152,53 Meter
Länge am Boden: 152,86
Richtung: 151,99 Grad

Illustration 7: Deviation alleged geo-position to actual position

Another test point was examined at the beginning of the video just before driving under the bridge. According to the video, the vehicle is at this time at 33 ° 26.0720 'N 111 ° 56.4719' W and actually about 76 m away from the actual position.

If one calculates the speed between the time bridge to accident based on these two geo-coordinate pairs, one obtains clearly deviating average speeds from the speed values shown in the video.

The pair of specified geo-coordinates is according to Google Earth a distance of approx. sGeo = 152 m. The couple of video determined geopositions results around sVideo = 179 m. According to time code in the video, the journey between these two points takes exactly t = 10 seconds. This results in the following speeds:

$v_{Geo} = s_{Geo/t =}$ 152 m / 10 s = 15,2 m/s = 54,72 km/h = 34 mph [14]
$v_{Video} = s_{Video/t =}$ 179 m / 10 s = 17,9 m/s = 64,44 km/h = 40,04 mph

The metadata contained in the video should therefore be handled with the utmost care - also with regard to the presumed calculated speed. This obviously refers to the area before driving under the bridge. In this area, a speed limit of 35 mph applies up to the bridge, which makes the calculated value vGeo of 34 mph plausible. The deviation or offset by approx. 76 m or 108 m on the driving beam is due to a delayed calculation of the speed based on outdated GPS data by a few seconds. The speed measured by GPS is always calculated from two previous geo positions and the time required for this. If the values are updated slowly, the thus determined speed always corresponds to that before x seconds. Using the video you can determine the coordinates of the impact very accurately by comparing the lane marking with the images from Google Earth:

Illustration 8: Mapping the accident using Google Earth

If one measures in the video the time, which needed the vehicle shortly before the accident for the departure of the distance of 6 middle trace marks, then this leads to a higher speed:

Distance measured with Google Earth 71.59 m (deviation in favour of the vehicle 70 m):

$v_1=s_1/t$ = 71,59 m / 3,52 s = 20,34 m/s = 73,21 km/h = 45,49 mph
$v_2=s_2/t$ = 70 m / 3,52 s = 19,87 km/h = 71,59 km/h = 44,48 mph

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[14] Conversion m/s in km/h: x 3,6 ; 1 mph = 1,60934 km/h

That means the vehicle has had a speed of about 45 mph in the last 70 m before the impact. According to the video (metadata), the vehicle accelerated in this area from 34 mph to about 40 mph directly on impact and then increased the speed to 42 mph after the accident. The latter is completely implausible, since that would mean that the car would have accelerated again when hitting the victim. In fact, it will have been slowed down by the impact. The findings on the previous page also explain this apparent contradiction. The speed values shown in the video, in contrast to the acceleration values X, Y and Z detected in real time, are outdated by several seconds and refer to the roadway about 76 m to 108 m further ahead of the accident. It is also plausible that the vehicle accelerated there, as the speed limit was raised from 35 mph to 45 mph from the time the bridge was driven under, as shown immediately.

Illustration 9: Front camera image about 120 m before the accident

Illustration 10: Front camera image immediately after impact

Illustration 11: Front camera image immediately after the impact

Illustration 12: Google Streetview Shot of the 45 mph sign by day

It is therefore very likely that the vehicle was between 42 and 45 mph at the time of the accident. Now, the police initially claimed that there is a speed limit of 35 mph at this point. Thus, the vehicle would have been automated too fast.

There are three proofs to the contrary, which all show that at this point 45 mph is the permitted limit and that the vehicle was not traveling too fast:

On the one hand, Google Earth provides in the Streetview view a completely clear picture of the signage in front of the bridge (about 200 m before the accident point). The picture is from July 2017 (well before the time of the accident).

However, even on the accident video, the 45 mph sign is easily recognizable:

Illustration 13: Recording of the 45 mph shield from the accident car

Moreover, on another on-the-internet video of the situation at night (recorded on March 21, 2018 by Brian Kaufman you can see the 45 mph limitation[15].

Illustration 14: Shot of the 45 mph shield from a reference vehicle at night.

From the same video, you can also see at the beginning of the ride that there is a 35 mph limit several hundred meters before the bridge crossing:

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[15] Note: Visibility in expression severely limited, better visible on the screen

Illustration 15: Take the previous 35 mph shield from the reference vehicle at night

Since this video also shows the area behind the accident, it becomes clear that after the 45 mph limit to the accident, there is no new deviating speed limit. This proves that there was a limit of 45 mph at the scene of the accident and not, as many erroneously claimed, 35 mph.

However, the video by Brian Kaufmann provides a much more important insight. The visual situation at night is not nearly as dark as the video broadcast by the police shows:

Illustration 16: Actual light situation at the accident site at night about 120 m before the accident

Illustration 17: Actual light situation at the accident site at night approx. 40 m before the accident

By counting the center markings and measuring the markings using Google Earth, you can also determine the average speed of the comparison vehicle here in connection with the time taken to drive off the track. This is about 40 to 42 mph and thus in about the same speed range as the accident vehicle. Therefore, you can put the videos well next to each other and determine the positions almost exactly (down to a few meters).

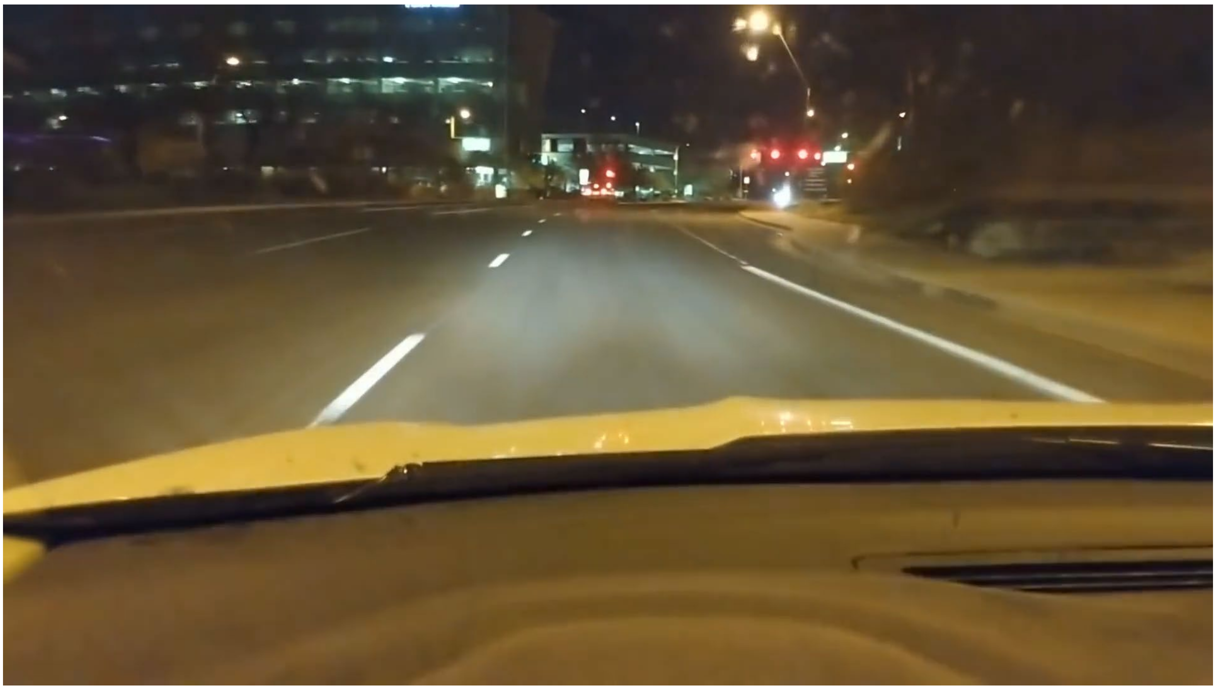


Illustration 18: Actual light situation at the scene of the accident

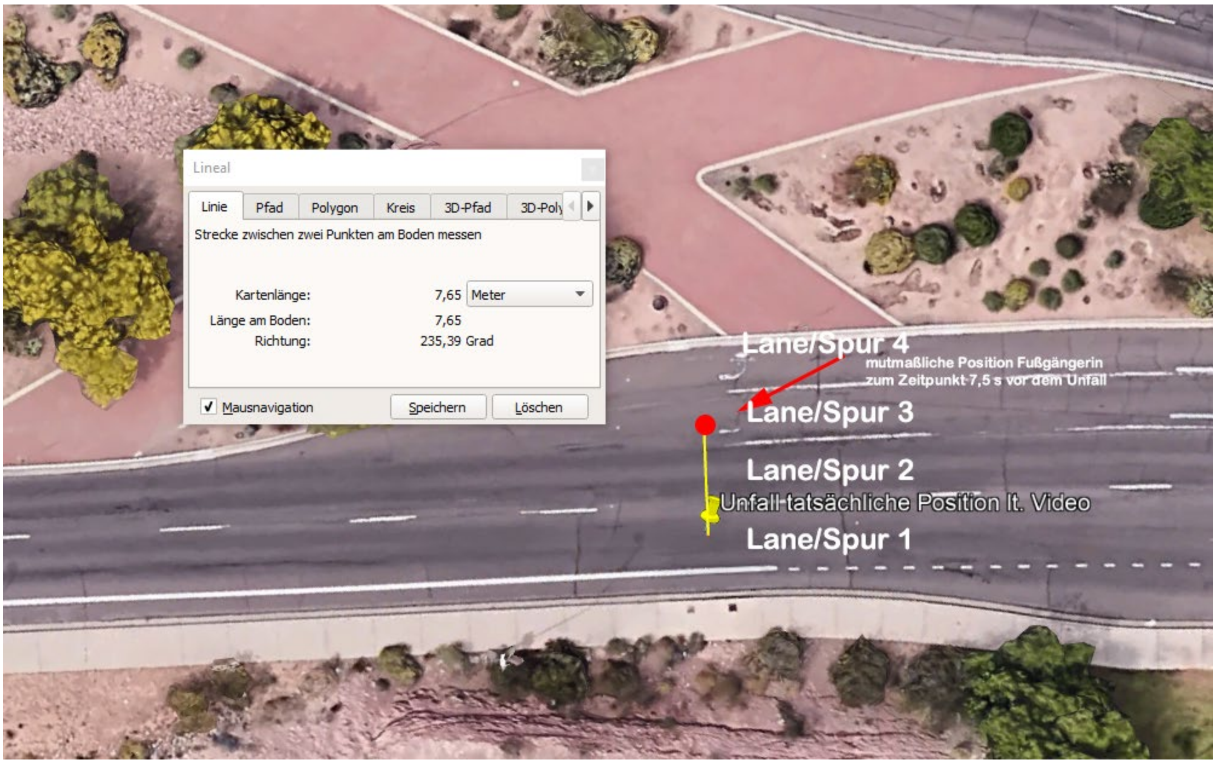
It can be clearly seen that the entire street is very well lit and an obstacle, such as a person crossing a bicycle pushing a bicycle would be easily recognizable.

In the Streetview view, Google Earth also provides valuable information about the situation at the scene of the accident (here of course during the day):

Illustration 19: Accident site by day (Google Streetview)

In the video provided by the police, it looks as if the woman with the bike would have been visible only about 1.5 seconds before the impact (time in the analysis video of the author of time code 00:00:12:19 to 00:00:14:05).

The video shows that she makes three steps from left to right in the right lane (lane 1) during this time. This corresponds approximately to a distance of 2.1 m (0.7 m per step). Thus, the accident victim moves with v = 2.1 m / 1.5 s = 1.4 m / s. Extrapolating this speed to the period before becoming visible in the direction to the left (from where it was presumed to come from), it has about 2.8 m (lane 2) 3 s earlier and about 5.6 m 6 s earlier (lane 3) further to the left.



Strecke zwischen zwei Punkten am Boden messen

Kartenlänge: 7,65 Meter
Länge am Boden: 7,65
Richtung: 235,39 Grad

☑ Mausnavigation

Illustration 20: Calculated movement of the pedestrian across the lanes

Therefore, the woman was already on the road at least 7.5 seconds before the impact. The vehicle was at the time of the worst-case 45 mph = 72.42 km / h = 20.12 m / s fast. Thus, it was located 7.5 seconds before the impact about 150 meters from the scene of the accident. This point is under the bridge:

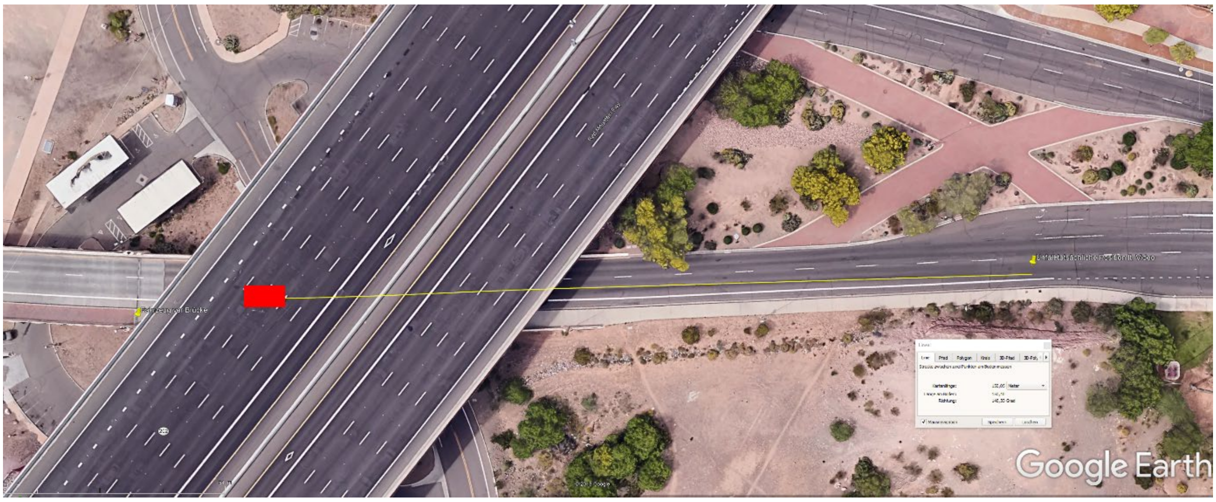


Illustration 21: Overview of the accident site via Google Earth

For further visualization, the author has assembled the videos / views on a screen, synchronized and provided with a time code.

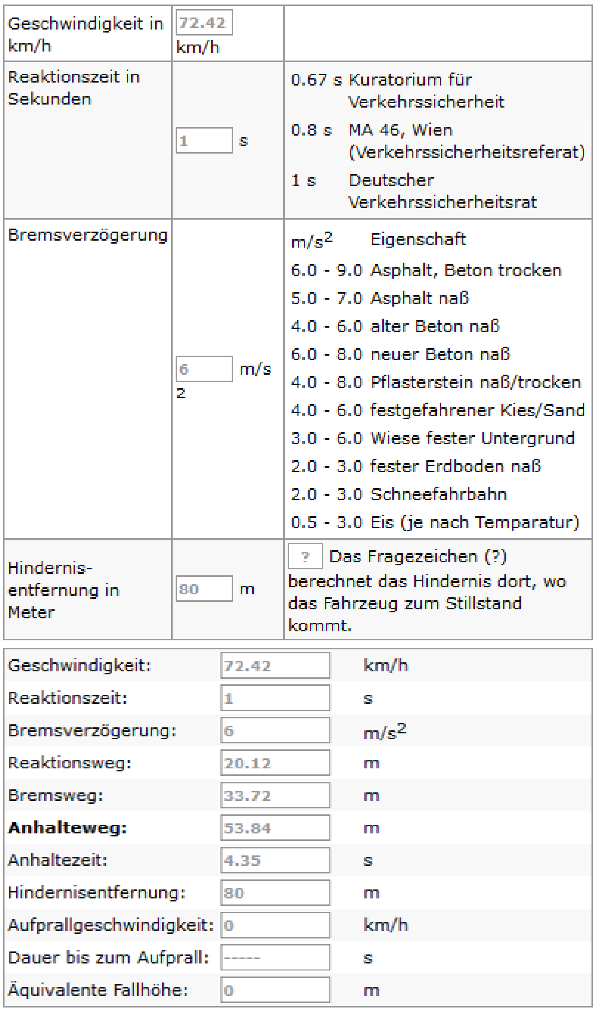
From the composite animation of the videos you can see that the driver of the Uber vehicle before the accident exactly at this point (time code 00:00:06:13) looked at the road for the last time and then did not look up until just before the impact.

Illustration 22: Composite and synchronized video presentation

The brighter comparison video shows that at that time the area of the turn lanes to the left of the main lanes was neither visible to sensors such as a LIDAR nor to a human driver. The woman was actually still in the shade of sight at this time.

Four seconds later (time code 00:00:10:13) and thus about four seconds before the collision (time code 00:00:14:05), the vehicle was still at least 80 m from the accident.

The stopping distance is calculated under unfavourable conditions (1 s reaction time, 6 m / s^2 for the minimum value of a delay in dry asphalt) to 53.84 m. That is to say, if the vehicle had made emergency braking at a time when the casualty must have been definitely visible at the latest, the vehicle would have come to a stop about 24 meters in front of the woman. Thus, it is also true that a reaction of the vehicle or the human driver at least 4.35 s before the actual impact would have been sufficient to prevent an accident. If one assumes in practice even higher possible deceleration values of 9 m / s^2 or more, the stopping distance is even reduced to 42.6 m.



Geschwindigkeit in km/h	72.42 km/h	
Reaktionszeit in Sekunden	1 s	0.67 s Kuratorium für Verkehrssicherheit 0.8 s MA 46, Wien (Verkehrssicherheitsreferat) 1 s Deutscher Verkehrssicherheitsrat
Bremsverzögerung	6 m/s^2	m/s^2 Eigenschaft 6.0 - 9.0 Asphalt, Beton trocken 5.0 - 7.0 Asphalt naß 4.0 - 6.0 alter Beton naß 6.0 - 8.0 neuer Beton naß 4.0 - 8.0 Pflasterstein naß/trocken 4.0 - 6.0 festgefahrener Kies/Sand 3.0 - 6.0 Wiese fester Untergrund 2.0 - 3.0 fester Erdboden naß 2.0 - 3.0 Schneefahrbahn 0.5 - 3.0 Eis (je nach Temparatur)
Hindernis-entfernung in Meter	80 m	? Das Fragezeichen (?) berechnet das Hindernis dort, wo das Fahrzeug zum Stillstand kommt.

Geschwindigkeit:	72.42	km/h
Reaktionszeit:	1	s
Bremsverzögerung:	6	m/s^2
Reaktionsweg:	20.12	m
Bremsweg:	33.72	m
Anhalteweg:	53.84	m
Anhaltezeit:	4.35	s
Hindernisentfernung:	80	m
Aufprallgeschwindigkeit:	0	km/h
Dauer bis zum Aufprall:	-----	s
Äquivalente Fallhöhe:	0	m

Illustration 23: Calculation of stopping distance and stopping distance[16]

In fact, the human driver first looked at the roadway a second before the impact and used up the entire one-second reaction time allowed to a human driver until a reaction was made.

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[16] Source: http://www.kfz-handwerk.de/bremsweg.php

Illustration 24: Synchronized video presentation at the time just before the accident

The impact is documented about 1 second later with time code 00:00:14:04.

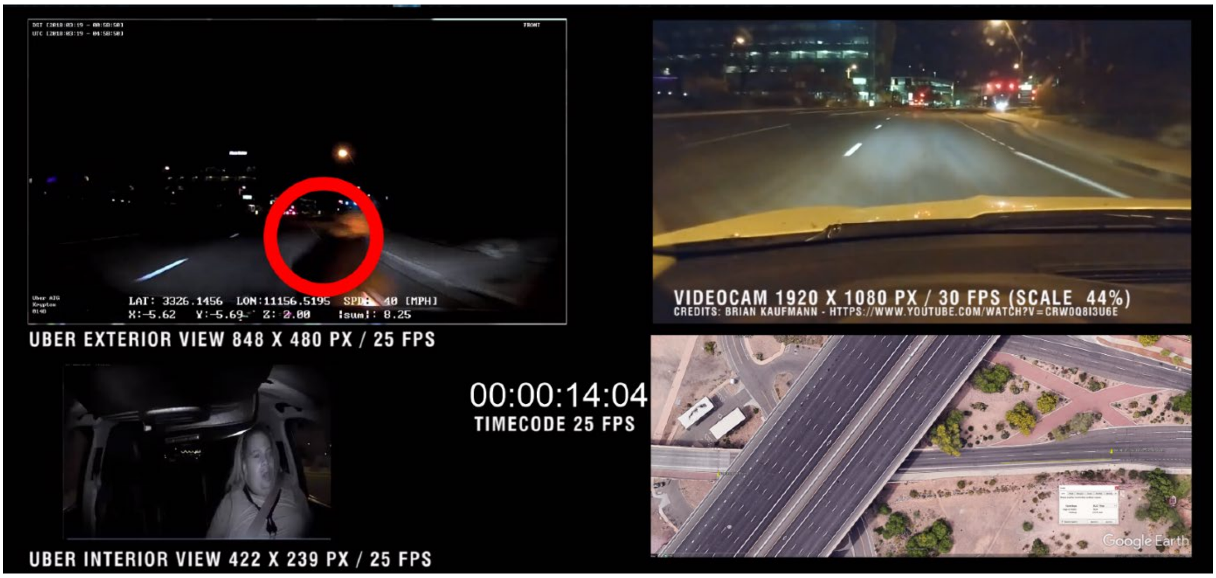
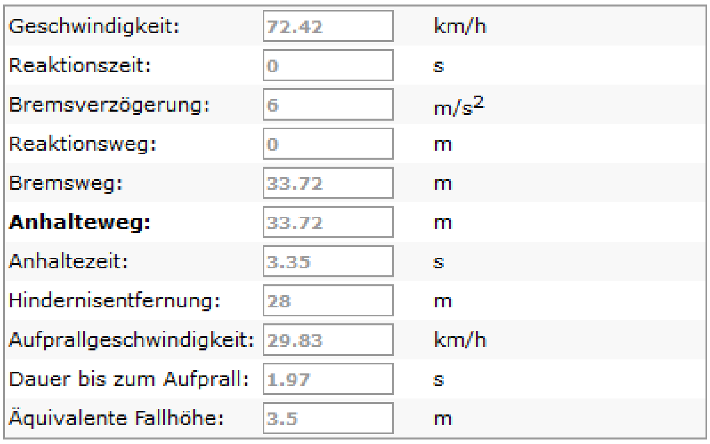


Illustration 25: Synchronized video presentation at the time of the impact

At latest at time code 00:00:12:20 and thus 1.4 seconds before impact, the victim is also visible in the dark video of the Uber vehicle and definitely in the detection range of the sensors themselves of a today in modern vehicles usual front collision warning on radar and / or camera base.

Illustration 26: Latest time to become visible in the police video

1.4 seconds before the impact, the vehicle still had a distance of at least 28 m to the accident victim. This would have led to an evasive maneuver against the direction of the woman and with a simultaneous braking to a pure braking distance of about 33.7 m. The residual velocity in a 28 m impact would have been just under 30 km / h instead of 72 km / h, resulting in less than a quarter of the impact kinetic energy. Possible meadow alone would have prevented the pedestrian from being fatally injured.



Geschwindigkeit:	72.42	km/h
Reaktionszeit:	0	s
Bremsverzögerung:	6	m/s^2
Reaktionsweg:	0	m
Bremsweg:	33.72	m
Anhalteweg:	33.72	m
Anhaltezeit:	3.35	s
Hindernisentfernung:	28	m
Aufprallgeschwindigkeit:	29.83	km/h
Dauer bis zum Aufprall:	1.97	s
Äquivalente Fallhöhe:	3.5	m

Illustration 27: Calculation of the pure braking distance and the impact speed

A successful avoidance even 1.4 seconds before the impact would have completely prevented the accident.

2.3 Conclusion

The coverage a few days after the incident was actually not only superficial, but actually came in many cases to the completely wrong conclusions. It is to be feared that the police will come to the wrong conclusions, if they do not evaluate the material as carefully and costly as the author. It is in any case recommended to carry out the evaluation using binary-identical copies of the original videos from the vehicle or to have them issued under the supervision of independent experts. The reason for the clearly too dark representation is clear in any case, since it is crucial for the assessment of the accident and its avoidability.

The following findings apply:

1. The accident vehicle was at least 42 mph and a maximum of 45 mph fast immediately before the accident and was thus within the permissible limit of 45 mph.

2. The video published by the police has been copied at least once lossy and overall much darker than the lighting conditions at the time of the accident have given. In fact, the accident site is more than adequately illuminated by street lamps and can be viewed over a distance of at least 80 m from the accident site via all lanes to the edges of the lane.

3. This range of vision of at least 80 m would have been sufficient for both an automated vehicle and a vehicle controlled by an average driver at the speed of max. 45 mph was perfectly enough to notice the pedestrian on the road and to come to a halt in time or to avoid her.

4. The human female driver of the accident vehicle, whose job it was to monitor the correct functioning of the fully automated vehicle, was distracted for at least six seconds before the accident and may have been looking at a smartphone or tablet. This can already be seen from the facial expression. In these six seconds, the vehicle has covered about 120 m, without a control of the driving task has taken place.

5. The sensor system of the fully automated vehicle has evidently shown no reaction to the pedestrian crossing the track and at no time braked or timely issued a warning to intervene for the human driver. Since the pedestrian has even pushed a bicycle, it can be assumed that this obstacle has given more than sufficient signal for both optical and laser, RADAR or ultrasound-based systems.

6. There is no noticeable delay before or during the accident in the video. Due to the lagging speed indicator in the video, it can be assumed that the vehicle was not 40 or 42 mph on impact but 45 mph fast.

These findings lead to three statements:

1. The provision or publication of the apparently unnatural dark video of the front camera leads to misinterpretation that the accident would have been unavoidable for a human driver and the accident victim unabated and suddenly stepped into the driveway. That is wrong and refuted.

2. The sensors or the control of the presumed fully automated vehicle has completely failed or was not turned on. Then the question arises who has kept the vehicle on the road at all. For further causal research, what has failed precisely in the vehicle, a complex forensic investigation of the vehicle is needed, which the author cannot afford based solely on the video recordings and publicly available sources.

3. The human driver has demonstrably failed to perform her control task and by her negligence did not recognize the failure of the sensors and thus did not prevent the imminent accident.

2.4 Evaluation of the theses from the previous publications

1. The injured pedestrian (who has pushed her bike across the lane) suddenly emerged from the shadows.

   This statement is so far wrong and refuted, since the pedestrian in the actual light and road conditions clearly visible has crossed the road and must have been at least 80 meters before the accident for man and machine recognizable.

2. The vehicle should have been traveling in fully automated mode at the equivalent of 64 km / h (40 mph) instead of the permitted 56.3 km / h (35 mph) at the accident site.

   This thesis is wrong. At the scene of the accident, 45 mph was allowed and at the time of the accident, the vehicle drove between at least 42 mph and a maximum of 45 mph.

3. The vehicle should have neither significantly delayed nor made an evasive movement.

   That is correct. There is no delay or evasive movement recognizable. Instead, even a slight increase in speed can be seen from the speed values shown in the video.

4. The driver on board the vehicle should not have intervened.

   This thesis is correct.

5. The accident would have been unavoidable even by a human driver.

   This thesis is definitely wrong. An attentive average driver could have easily prevented the accident by braking and / or evading early. The same applies to a fully automated moving vehicle, if its sensors and control had worked properly.

6. The police from Tempe, Arizona (Sylvia Moir) said that it looked like Uber was not to blame for the accident and charges against the driver were not ruled out.

This thesis is not tenable. Undoubtedly, the driver has drastically violated her duty of control, as she has not looked at the road for at least 6 seconds and around 120 m of road ahead of the accident. In fact, the vehicle should have recognized the pedestrian and had to react to it. Since this did not seem to happen, it is now to be clarified who is responsible for this mistake (Uber, Volvo, supplier).

7. The vehicle was equipped with RADAR sensors, cameras and a LIDAR system.

   The statement will be correct, but cannot be checked objectively by the author.

8. On 27/03/2018, Uber was withdrawn from the permit for further test drives with autonomous vehicles until further notice.

   The statement will be correct, but cannot be checked objectively by the author.

9. Uber equipped the vehicle with its own hardware or software and switched off the standard collision system from Volvo.

   The examination of this thesis will be elementary for the further cause research and school investigation.

2.5 Summary

From this accident, one can thus draw two lessons:

1. Tests of fully automated moving vehicles in regular traffic are only allowed under continuous and continuous review by an attentive human driver who is not allowed to perform any other duties or sidetasks while driving.

2. The commissioning of fully automated or autonomous moving vehicles has to be omitted if, for "safety reasons" still a human should ride along for observation. Either the vehicle can master each situation completely independently or not. A fallback to a human driver cannot exist in an autonomous vehicle by definition. In addition, the example of the Uber crash has sadly shown that a backup driver engaged in a sidetask cannot intervene quickly enough if the vehicle gets into a situation that cannot be solved by itself or into an undetected dangerous situation.

The social acceptance of a fatal accident caused by a machine, which a human being could easily have avoided, is close to zero and thus jeopardizes the entire project for automated and autonomous driving.

2.6 Further reading

For the interested reader, the entire research report Car-Forensics is recommended, which deals intensively with IT security and functional safety in the context of the modern automobile (unfortunately only available in German).

The research report is available in the updated fourth edition for a price of € 280.00 as hardcover and € 259.99 as an eBook from Books on Demand or www.car-forensics.de (German only).

With the purchase price, you support the research work Car-Forensics, which was financed entirely by private means without public funding or support from car manufacturers.

3 Appendix

3.1 List of figures and tables

3.2 Literature and source list

Autobild. (2018). Uber erhält Fahrverbot für Testfahrte. Retrieved from http://www.autobild.de/artikel/autonomes-fahren-toedlicher-unfall-von-uber-13410181.html

Bloomberg. (2018). Wake up call for autonomous vehicles. Retrieved from https://www.bloomberg.com/news/articles/2018-03-22/video-said-to-show-failure-of-uber-s-tech-in-fatal-arizona-crash

Coppola, G., & King, and I. (2018). Uber Disabled Volvo SUV’s Safety System Before Fatality. *Bloomberg*. Retrieved from https://www.bloomberg.com/news/articles/2018-03-26/uber-disabled-volvo-suv-s-standard-safety-system-before-fatality

Forbes. (n.d.). Uber Tempe Video Shows A Crash Self-Driving Cars Should Be Able To Avoid -- Time For Regulations. Retrieved from https://www.forbes.com/sites/samabuelsamid/2018/03/21/uber-crash-tape-tells-very-different-story-from-police-report-time-for-some-regulations/#3d15f36648df

Network, U. T. (2018). Tempe police chief: Fatal Uber crash likely “unavoidable” for any kind of driver. Retrieved from https://www.azcentral.com/story/news/local/tempe/2018/03/20/tempe-police-chief-fatal-uber-crash-pedestrian-likely-unavoidable/442829002/

Newsweek. (2018). Tempe Police Release Footage of Fatal Uber Self-driving Car Collision. Retrieved from http://www.newsweek.com/police-release-video-fatal-uber-self-driving-car-collision-856526

Spiegel. (2018). Arizona verbietet Uber weitere Testfahrten. Retrieved from https://www.google.de/url?sa=t&rct=j&q=&esrc=s&source=web&cd=4&cad=rja&uact=8&ved=0ahUKEwjZ_dLLzo_aAhWLKFAKHYZXC_sQFghBMAM&url=http%3A%2F%2Fwww.spiegel.de%2Fauto%2Faktuell%2Fusa-uber-darf-selbstfahrende-autos-nicht-mehr-in-arizona-testen-a-1200008.html&usg=AOvVaw0T3JW1v41sNdI7PZcC6Tj6

WDR. (2018). Uber-Unfall unvermeidbar? Retrieved from https://www1.wdr.de/wissen/technik/uber-unfall-blogbeitrag-100.html

3.3 Additional offers

3.3.1 Further information and updates

On the website https://www.car-forensics.de as well as in the blog https://blog.Kaeferlive.de you will find regular updates and news around the topic "digital forensics". A professional exchange is possible through the Xing group "Car-Forensics", which is initiated and moderated by the author: Link: https://www.xing.com/communities/groups/car-forensics-c60d-1077565 .

Further publications (excerpts – German only):

- Professional article series DigiFor Inside 1-3 (2014)
- Computer Forensics: Analysis of Attacks (TecChannel Compact 04/2004)

3.3.2 Lectures and media coverage

The author reports on the results of the research (e). at the following events, (see also https://www.kaeferlive.de/index.php/events):

- 10.08. until 10.10.2018 Car Forensics at the 27th Aachen Motor and Vehicle Colloquium of FKA and IKA of the RWTH Aachen
- Car-Forensics at the Science-Link: Networking 4.0 "Data security in autonomous driving" on 19/03/2018 in Aachen
- Speaker at the IT Security Fair Leetcon Hannover in November 2016
- Economic news of the IHK Aachen 11/2016
- Speaker at the Aachen Vehicle and Engine Technology Colloquium of the RWTH Aachen - Lecture on IT Security in the Automotive Industry October 2015 and 2016
- Speaker at the IT-Security Breakfast of the IHK Bonn September 2016
- 11.12.2015: Aachen Interdisciplinary Traffic Symposium
- 02.12.2015: IT Security Industry 4.0 at the IT Security Day NRW
- 06.11.2015: Speaker Car-Forensics at the IT Security Breakfast Bonn
- 21.-22.10.2015: Poster Car-Forensics at the Automotive Security 31st VDI / VW-Community Conference in Wolfsburg
- Professional portrait Digital forensic scientist in the VDI Nachrichten of 09.10.2015
- 06.10.2015: Hausmesse Wolfsburg - Presentation on IT security in motor vehicles
- ARD Tagesschau and WDR Current hour Statement on the VW exhaust software (22.09.15 and 25.09.2015)
- ARD Plusminus extra opinion on the VW exhaust software (21.09.2015)
- MDR fact is ...! BMW Hack (21.09.2015)
- ARD tagesthemen from 23.07.2015 to the jeep hack / BMW hack
- 12.05.2015: Speaker IT forensics workshop at the FH-Aachen
- WDR television local time Aachen from 08.05.2015
- Car-Forensics in the magazine Mobile Business 03-2015
- 16.03.2015 - 20.03.2015: CeBIT - Speaker Car-Forensics
- 03.12.2014: Speaker IT Security Hagen - IT Security Day NRW 2014
- 24.11.2014: Speaker Digitale Kfz-Forensik - Cologne - cologne IT summit
- 16.09.2014: Speaker Car-Forensics 9th Dortmund Autotag
- Car-Forensics in the Aachen news from 21.07.2015 and 15.09.2015
- Digital forensics in the innovation magazine "Technology Review" 07/201
- Where the car developers of the future come from in "Die Welt" from 23.06.2015

3.3.3 Workshops

The author offers full-day and multi-day training courses and workshops on digital forensic forensics.

Seminar concept: The seminar "Car-Forensics - Automotive Security" is based on and is based on the research project of the same name and should take account of the aforementioned aspects and show what is technically in the field of forensic evaluation of the built in the car or externally with the Vehicle-coupled IT systems is already possible and conceivable in the future. In this context it will be examined which legal bases are currently available and applicable and where there is a need for regulation on the part of the legislator in the near future. In the practical part, it will be discussed which interfaces the various systems possess, which can be addressed or evaluated forensically. Here, both openly communicated standards and accesses are accessed as well as e.g. using hacking and analysis tools with the help of reverse engineering methods, a data analysis or manipulation tries. By means of digital forensics and typical attackers, concrete examples from the automotive environment and the Internet of Things will demonstrate the extent to which technical and organizational security measures can be circumvented in order to eliminate access safeguards or which data is actually transmitted and stored.

Objective: In the seminar the topics data protection and data security from the point of view of the operators and users as well as the forensic possibilities and rights for experts and investigators are examined. Furthermore, a code of conduct for Car2X communication is discussed. The findings from the various hacker attack scenarios and tools can be used by development engineers to harden the systems not only in terms of functional but also and above all IT and data security.

Target group: The seminar is aimed equally at developers and operators of automotive systems (hardware and software) as well as at decision makers who have personal and development responsibility in this area (OEM and supplier).

Prerequisites: Previous knowledge in the area of software and system development as well as IT security is desirable, but not mandatory. In the seminar we try to consider the topic Car-Forensics in the broadest and where necessary and meaningful in the required depth.

Please see the following link for a compilation of Car-Forensics media: https://www.youtube.com/watch?v=dhK2LhIV3Uk