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Test Plan of Collision Warning for Road Traffic in Smart Cities

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Abstract

Urban road traffic comprises many different road users like heavy trucks, buses, individual cars, motorbikes, (E-)bikes, and pedestrians. The latter are among the vulnerable road users (VRUs), whose safety and protection on the road are of special social interest. Since it can be assumed that not all vehicles will be equipped with comprehensive sensor technology, such as the kind that is required for autonomous driving in the next few years, and since such technology is hardly feasible for VRUs, appropriate infrastructure-based sensor technology will have to be used to detect critical traffic situations. Special cameras with integrated image analysis for data protection-compliant recognition in combination with a mobile 5G-based cloud application and smartphone apps are suggested for this task. If there are potential collisions, timely collision warnings have to be received by the road users and VRUs. A test plan for evaluating the collision warning system for a complete end-to-end (E2E) system test is defined during the planning phase of the project 5G-trAAffic that includes both functionality and accuracy tests is described in this paper. The tests show that there is a significant difference in the precision between several types of smartphones and applications that are used. The complementary algorithm and processing to get the best performance and the best accuracy should be implemented in general cases including several types of smart phones.

Keywords: Smart City, Road Traffic, Collision Warning, Positioning, 5G

Introduction

The number of passenger cars has increased in the past decades and currently (as of Jan. 2024) amounts to around 49.1 million in Germany [1]. As the number of road users increases, so does the potential risk of accidents. In urban traffic, a large number of different road users are encountered, such as trucks, buses, cars, motorbikes, (E-)bikes, and pedestrians.

The latter are among the vulnerable road users (VRUs), whose safety and protection are of special interest.

Urban intersections in particular often represent a major accident hotspot.

Despite the efforts of numerous national and international programs and technological progress, the vision of zero traffic accidents (“Vision Zero” [2]) remains a major challenge.

At present, 5G mobile networks are being deployed in many regions. This generation of mobile communications incorporates higher reliability, lower latency, and enhanced vehicle-to-everything (V2X) functionalities, compared to its predecessors. This opens new potential that can also contribute to improving road safety.

Since it can be assumed that not all vehicles will be equipped with comprehensive sensor technology, such as the kind that is required for autonomous driving in the next few years and since such technology is hardly feasible for VRUs, appropriate sensor and actuator technology has to be established.

In the project “5G-trAAffic” [3], a combination of infrastructure-based sensors or/and smartphones equipped with a dedicated app are proposed to detect critical traffic situations to protect road users.

In particular, cameras with integrated image analysis for data protection-compliant recognition (i.e., “AI cameras”) in combination with a mobile 5G-based cloud application and the smartphone apps are suggested in [3]. If there are potential collisions, timely collision warnings have to be received by the road users and VRUs. These warnings are to be sent via the app as well as via infrastructure-based optical or acoustic warning devices at key hazard points in order to warn road users without an app [3].

A test plan for evaluating the collision warning system for a complete end-to-end system test is defined during the planning phase of the project 5G-trAAffic that includes both functionality and accuracy tests, a part of which is described in this paper. The focus in this paper is on investigations into the accuracy of the positioning without the help of cameras.

This paper is organized as follows: In the following section, related work including standards, research projects and scientific work will be presented. This is followed by a section related to the general test plan approaches in this project. Initial testing and associated results gained at a Smart City campus are described thereafter. The measurements of the positioning accuracy of various smartphones, each with two different apps in the context of collision warning, are then presented in detail. Finally, a conclusion and an outlook are shown.

Related Work

Within the last five years, more than 400 research projects on traffic were funded solely by the “mFund” program of the German Federal Ministry for Digital and Transport (german: Bundesministerium für Digitales und Verkehr) [4]. Most of these projects address aspects of traffic management, still many aim at the protection of vulnerable road users, especially in the vicinity of intersections.

As examples, a few of these similar projects are mentioned below: in particular, as part of the "TAVF (Test Track for Automated and Connected Driving in Hamburg)" a few similar projects [5]:
The project "5G-Loginnov" [6,7] addresses innovations by the usage of 5G technology related to the area of ports. One aspect of this is how 5G can enhance hybrid V2X communications and intelligent traffic management. As one aspect, the protection of VRUs by an app-based collision warning service is investigated [6,7].

To assess the literature of collision avoidance system in intelligent traffic systems (ITS), a set of performance criteria are provided. As a first step, the safety assessment as the key concept in this area should be explained. It is known as a process of the considered participants and moving objects in the assessed area e.g., the intersection to find dangerous conditions and hazard location which leads to predict probable crashes. This results in a large number of sub-aspects such as communication (e.g. V2X), mobile edge cloud computing, positioning accuracy, computer vision, multi-sensor data fusion as well as non-technical aspects such as the consideration of laws and (traffic) regulations through to traffic psychology. A selection of related technical work is summarized below.

In the early work [8], a prototype of pedestrian-to-vehicle communication system for the prevention of pedestrian accidents was developed. As this prototype was published already in 2008, it is based on the 3G and WLAN standards of the time, whereby (C-)V2X in particular was not yet sufficiently developed and standardized. However, already an algorithm for estimating the collision risk and the need for caution was developed and the system could exchange information between pedestrians and vehicles with enough time and distance to avoid the collision in that work.

In the paper [9], a collision avoidance service between vehicles at an intersection is presented. Thereby, the service is implemented on a Multiaccess Edge Computing (MEC) infrastructure. The end-to-end delay is computed considering standardized Cooperative Awareness Messages (CAM) for different scenarios. In all scenarios, 80% of the end-to-end latency values were below 45 ms and latency values were recorded to be lower than 60 ms in 99.999% of the cases [9]. In conclusion, it has been shown that communication can essentially take place quickly and reliably enough.

Numerous recent publications address the positioning accuracy of smartphones, e.g. [10-13]. In [10], an augmentation system for ionospheric corrections was evaluated, using a smartphone as GNSS receiver. Evaluation different methods, finally horizontal positioning accuracies between about 0.8 m to 2.3 m could be reached. The positioning performance of a smartphone using (only) a single-frequency GNSS receiver chip was evaluated in [11]. If utilized as single-point positioning system, a pseudo range single-point positioning error of up to 100 m along a track was observed. However, using an RTK (Real

Time Kinematic) approach provided by a reference GNSS receiver, the positioning error of the smartphone could be lowered below 5 m in most test cases. The accuracy of vehicles mutual positioning was examined in [12]. Therefore, two cars equipped with smartphones drove on different road types and performed maneuvers like overtaking, advancing, etc. Utilizing a filter algorithm, a relative positioning error between 1.9 m to 2.6 m (standard deviation) could be achieved. In [13], the performance of poisoning algorithms of GNSS and 5G for smartphones was evaluated. Using simulations for the 5G network, positioning errors below 0.5 m, each in latitude and longitude direction was achieved.

In [14] the accuracy of GNSS receivers is evaluated. Using quasi-multiple measurements obtained from different GNSS receivers with integrated inertial measurement units (IMUs) and combining their individual outputs, the position uncertainty could be significantly reduced to final uncertainty in the order of one centimeter (standard deviation) along street railway tracks. Consequently, a sufficiently high level of accuracy can be achieved with a correspondingly high level of effort and the use of special hardware.

The ETSI (European Telecommunications Standards Institute) has developed various standards for (C-)V2X communication and intelligent traffic systems (ITS) [15].
The 5G Automotive Association (5GAA) as an association of car manufacturers and telecommunications companies, addresses aspects and services of connected driving. Among other things, system requirements defined for various applications. These also include requirements for positioning accuracy in the context of various safety-relevant applications [16], which will be discussed in more detail below.

Test Plan and Setup

The test plan and the setup mainly depend on the requirements of the collision warning system. To check the accuracy of the collision warning messages, the ratio of “true positive” warnings (warning sent when a collision is expected), the ratio of “false positive” warnings (warning sent when no collision is expected), the ratio of “true negative” warnings (no warning sent when a collision is expected) and the ratio of “false negative” warnings (no warning sent when no collision is expected) are measured in this step. Additionally, they also assess whether the warnings are issued on time.

Further collision warning scenarios that are covered by the test plan are car versus bike, car versus pedestrian, bike versus pedestrian, and bike versus bike. Each scenario has various permutations in terms of position, velocity, and other movement patterns of road users.
Some requirements can be considered as following: the position, dimension, velocity, and direction of actors shall be calculated and the position accuracy shall be better than 50 cm, according to [15]. For location sensors, an allocated reference position shall be provided.
An appropriate visible scene or detecting area shall be provided by the sensor e.g., the camera shall have a vision distance of at least 100 m. Also, the sensors shall operate under all weather and light conditions. Data transfer of the sensor shall be provided by a 5G link which has the proper capacity for data transmission and sufficient low latency.

In the 5GAA Whitepaper [16], the service level requirements for different use cases are derived, including requirements for position accuracy. Depending on the use case, the values vary. For the use case of Hazardous Location Warning, [16, Sect. 4.7] a position accuracy of 1.5 m (3 sigma) for lane-specific information and 5 m (1 sigma) non-lane-specific information is required.
For the use case of a “Cross-Traffic Left-Turn Assist”, also 1.5 m (3 sigma) are listed [16, Sect. 4.1]. However, for “the use case of “Vulnerable Road User” [16, Sect. 4.12] an accuracy of 1 m (3 sigma) is required with the following note: “In order to correct positioning based on GNSS (e.g., GPS, Galileo), this accuracy should be enhanced via the 3GPP System. The 3GPP System shall provide positioning accuracy of 1 – 2 m, […]”.

Addressing the whole accuracy which includes calculating the precise location of the VRUs and location of cars, the first step is measuring the accurate location of road users.
The initial test field was set up at ZDE Smart City Campus in Westhausen. On the large parking lot available at the campus (approx. 55 m by 40 m) the entry situation of Rathaustiefgarage Aalen was reproduced with semi-permanent tape markings on the ground. 3 car lanes and a bike line crossing the garage entry and exit car lanes were projected on the ground and reproduced. Reference points were defined and marked. These points have

then been digitally surveyed with a precision of 2 cm. For campus layout see Figure 1.

On the test site, two AI cameras were mounted on a mobile pole (6.3 m high, placed in the same position as an available pole in the real setup) and pointed to two relevant sections. Angles were reconfigured and optimized several times during the testing process. Simulated traffic users were equipped with 5G smartphones. Uplink of the cameras and smartphones was transmitted through the 5G campus network available from ZDE.

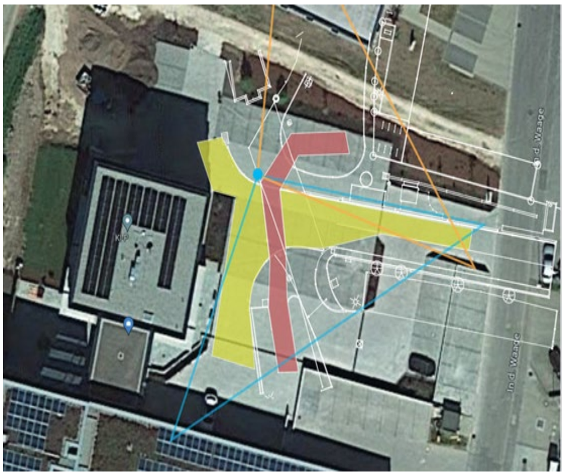

Fig. 1: Smart city campus test site plan of ZDE in Westhausen. The red area represents a cycle-/foot path and the yellow area represents a street / Underground parking garage entrance. The blue- and orange line triangles indicate the visible areas of the observing cameras. (This figure was created by ZDE and contains material from Google.)

During the initial tests, the overall system was successfully put into operation and thus the basic functionality could be confirmed.

However, the initial tests also identified issues that need to be addressed for further development. Overall, it was found that, when viewed in isolation, the AI cameras sometimes produced better results and sometimes the smartphones. In addition, there were significant deviations in the position between different smartphones, which gave rise to further investigations. To understand the capabilities of geolocation accuracy, further tests were planned outside of the ZDE Campus.

This collection of tests was designed to explore the performance of multiple smartphones and applications over various routes, each differing in length. Given the lack of suitable geolocation references in this specific area, the necessity to devise an original framework became apparent. This led to the integration of the Starling Precision GNSS Module Evaluation Kit (PGM EVK) [17], a component that has used in similar projects like 5G-Loginnov. The device is distinguished by its capabilities to provide real-time precision GNSS and IMU measurements and is enhanced by Swift's Skylark cloud-based precise corrections service [17]. For optimal results, a magnet-mount antenna was placed on the roof of the test vehicle - ideally as close to the center as possible - to ensure an unobstructed view of the sky, with the PGM EVP situated directly underneath inside the car (Figure 2).

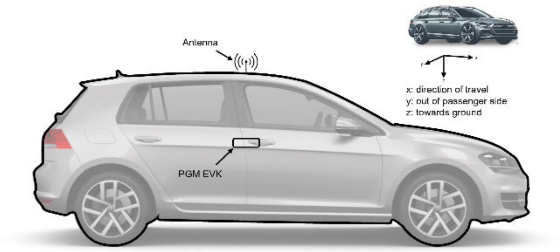

Fig. 2: Mounting of the antenna an the roof and the PGM EVP in the car.

The evaluation extended to a variety of smartphones, including the iPhone 13 Pro, OnePlus 9 Pro, Samsung S21 5G, Oppo Find X3, Oppo Find X5, and Motorola moto g 5G Plus. This selection was aimed at covering a wide range of manufacturers and thereby gauging the performance across different hardware. The applications chosen for this test were LCMM (Low Carbon Mobility Management), developed by T-Systems International and DSA (Digital Safety Assistant), developed by Continental, representing tools with potential implications for mobility and safety.

Additionally to the equipment used, the routes were selected to provide a diverse set of data points:

The “long route” solely focused on the comparison between LCMM's performance on different smartphones and the Starling PGM. The route is shown in Figure 3 and corresponds roughly to a mirrored "L" with a short section running east-west (almost in latitude direction) and a longer section running mainly north-south (longitude direction). A car was driven back and forth along this route three times and test data was recorded.

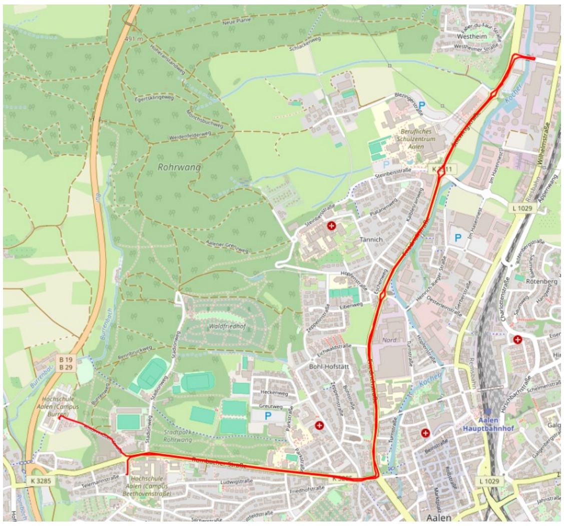

Fig. 3: Long route across the city of Aalen (background map: OpenStreetMap contributors).

The "short route" (Figure 4) included a stretch from the intersection at Friedrichstraße/ Gartenstraße to the administrative district office in the City of Aalen, facilitating a direct comparison among DSA and LCMM (simultaneously) as well as the Starling PGM. This route was also traveled three times by car.

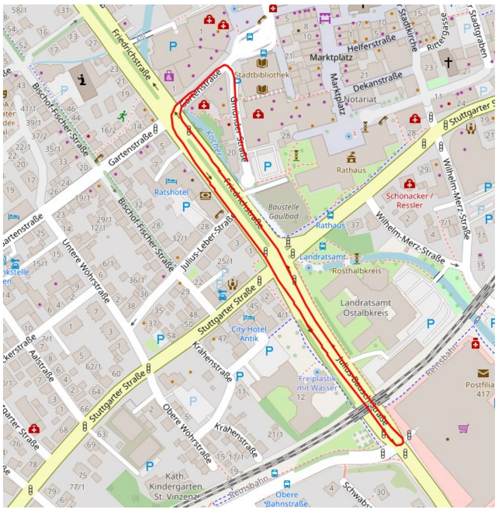

Fig. 4: Short route across the city of Aalen (background map: OpenStreetMap contributors).

Results

The primary goal of this test setup was the collection and analysis of data that would allow for a meaningful comparison between the various smartphones and applications. Specifically, the tests were aimed to determine the accuracy levels of manufacturers and ascertain whether different applications yield disparate results when tested on the same device. This test endeavors to provide an insight into the precision of GNSS measurements across different technologies, potentially leading to conclusions for further tests.

In order to measure the drift of the position of the PGM EVK over time, it was set up at a static location and the position was recorded over time. Figure 5 shows the horizontal distance to the median recorded position over a time period of 40 minutes, which corresponds to slightly more than the test drives. Overall (despite cloud cover and rain on the day of the measurement), a horizontal distance to the median position of below 0.35 m was maintained. This value is considered as precise enough and thus taken as reference for further measurements and comparison.

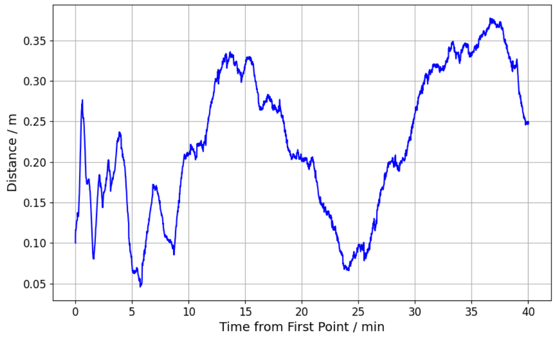

Fig. 5: Horizontal difference to the median position over time of the PGM EVK.

Further measurements were taken while the vehicle was moving (i.e., "drive tests").

The Starling PGM EVK is equipped with a function to estimate the accuracy of the output function. The histogram of the horizontal accuracy (i.e., combined in longitude and latitude direction) during drive tests is shown in Figure 6. The median is below 0.2 m and 99% of the estimated accuracy values are below 0.4 m. This accuracy also fulfills the requirements of ETSI [15] and 5GAA [16], as stated before. The next step was to compare the various smartphones with the PGM EVK during the test drives.

Figure 7 and Figure 8 show examples of the deviations of the logged position of various smartphones with the LCMM app for a test drive (long route). The (approximate) point symmetry to the center of the recording with the positive and negative values results from the outward and return journey and from the fact that no absolute value was calculated in this case.

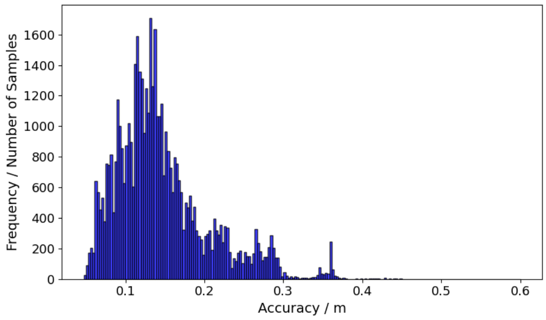

Fig. 6: Histogram of the estimated horizontal accuracy of the PGM EVK, calculated over all drive tests.

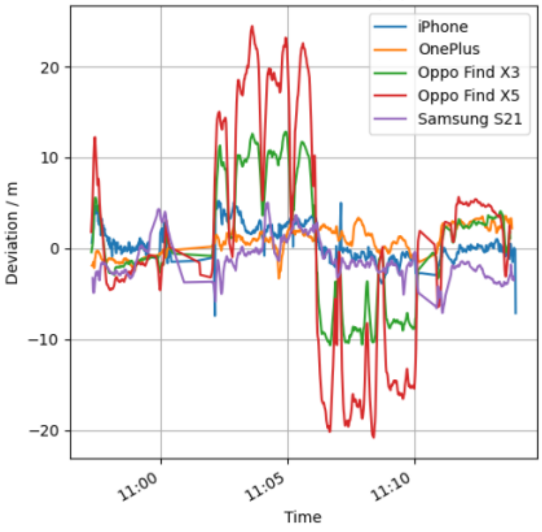

Fig. 7: Latitude deviation using LCMM app.

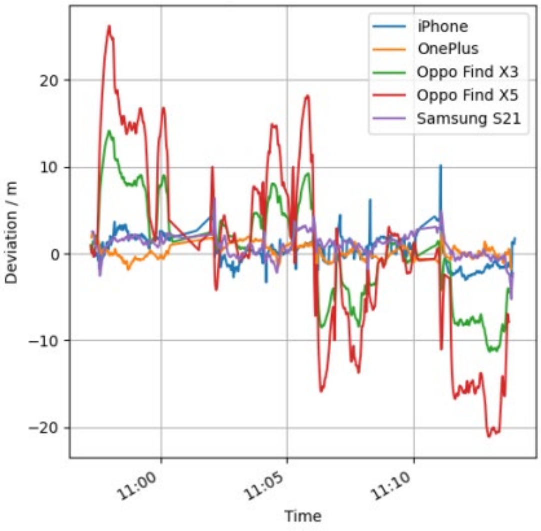

Fig. 8: Longitude deviation using LCMM app.

The accuracy of the smartphones sometimes differs significantly and varies over time and distance/position. In some parts of the route, some smartphones show very large deviations of more than 20 m. It is noticeable that at certain times or route sections the deviation is large either in the latitude direction or in the longitude direction. A linear progression over time occurs when the vehicle comes to a standstill, which are recognized by the LCMM app and during which no new waypoints are recorded. Other test drive with the LCMM lead to similar results.

Table 1 shows the root mean squared deviation (RMSD) for the LCMM app in latitude and longitude direction over all test drives.

For all smartphones, the RMSD in latitude direction was lower than in longitude direction.

Possible reasons for this behavior might be narrower street and shadowing during the route section in latitude direction of the long route. While the RMSD for all other smartphones is in the order of 2 m to 3 m, the Oppo smartphones perform worse with LCMM app.

Tab. 1: Average of RMSD over the trials (test drives) for each smartphone, using the LCMM app.

Phone (using LCMM)	Average RMSD Latitude / m	Average RMSD Longitude / m
iPhone 13 Pro	2.57	1.81
OnePlus 9 Pro	2.28	1.73
Oppo Find X3	5.80	5.23
Oppo Find X5	10.89	9.40
Samsung S21 5G	2.78	1.86

The absolute values of the position deviations to the PGM EVK recorded by the smartphones using the DSA app are presented in Figure 9 and Figure 10 (short route). Generally, the deviations are in the same order of magnitude as with the LCMM app. Again, there are significant differences between the accuracy in latitude and longitude direction. However, the Oppo Find X5 and Oppo Find X3 perform more accurately with the DSA app. In contrast, the Samsung S21 5G has less accuracy in this particular test drive.

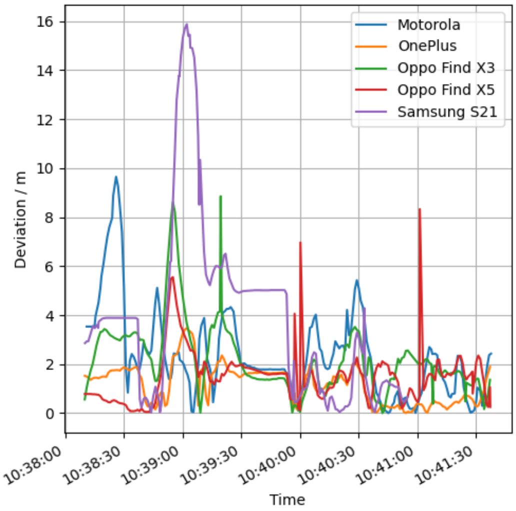

Fig. 9: Latitude deviation (absolute value) using DSA app.

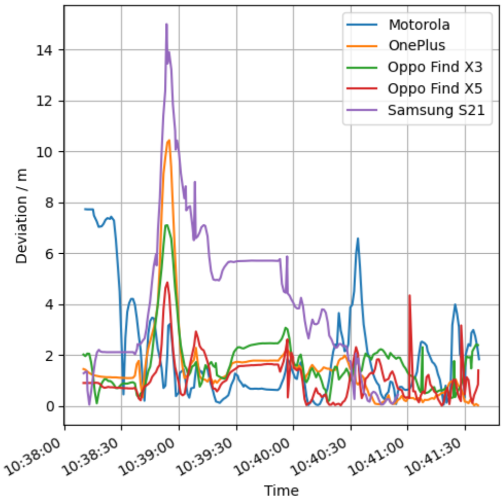

Fig. 10: Longitude deviation (absolute value) using DSA app.

Figure 11 shows the total horizontal deviation for both apps as comparison.

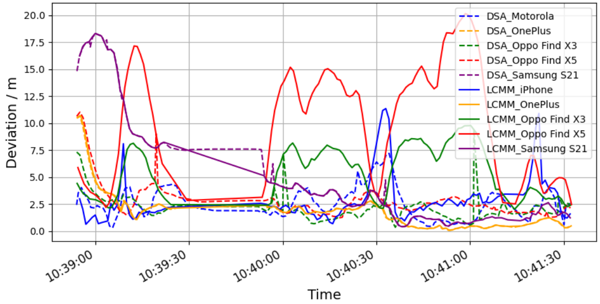

Fig. 11: Comparison of horizontal deviation between LCMM and DSA.

Some devices, like the OnePlus 9 Pro provide almost the same performance with each app. In contrast to this, the Oppo smartphones had a significantly reduced accuracy if using the LCMM app. For almost all smartphones, there are outliers with significantly reduced accuracy. Overall, there are smartphones that perform slightly better on average. Table 2 lists the average of RMS horizontal deviation for both apps. Apart from the exceptions Oppo Find X3 / X5 with LCMM app and Samsung S21 5G, all values are between 3 m to 4 m.

Tab. 3: Average RMS deviation for LCMM and DSA app (= not measured).*

Phone	LCMM app RMS / m	DSA app RMS / m
IPhone 13 Pro	3.26	-*
OnePlus 9 Pro	3.18	3.41
Oppo Find X3	6.23	3.86
Oppo Find X5	11.40	3.87
Samsung S21 5G	6.76	6.69
Motorola moto g 5G Plus	-*	3.26

Conclusion and Outlook

Based on the test plan for an infrastructure and mobile communication based collision warning system, the position accuracy of smartphones was examined in detail. For this purpose, different smartphones with two different apps were analyzed. Apart from individual combinations, an average accuracy of 3 to 4 m (RMS horizontal) was achieved in most cases compared to the reference value. This achieves sufficient accuracy for the 5GAA use case “Hazardous Location Warning” (non-lane specific). However, for the collision warning use cases, a higher (average) accuracy would be desirable. In addition, especially in the area of intersections and accident hotspots, no inaccuracy peaks should occur to enable a reliable service.

As an outlook, there is an overall need to improve accuracy and reliability. One approach is to integrate AI cameras into the overall system with improved algorithms for sensor data fusion. Another approach is the integration of data from modern vehicles, which already have numerous sensors for precise navigation.

In future tests that include smartphones, there should be multiple phones of the same make and model to rule out that deviances in the data collection are due to a fault sensor or smartphone specific issues. In addition, improved performance can be expected in the future through the availability of 5G and beyond technologies, which promise their own localization, so that a reliable collision warning system at intersections can be realized in the future.

Acknowledgement

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