TEST PROCEDURES FOR ACC-SENSORS

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SUMMARY

The search for new vehicle systems that relieve the driver in his activities has led to the Adaptive Cruise Control (ACC). An essential component for the system's function is the distance sensor that enables the observation of the vehicle environment. With this article, it can be shown the possibilities for the assessment of sensors for ACC-systems but also comparable systems that also need sensors for observing the environment. The basis for this is a test method that is derived from the requirements depending on the employment in terms of an objective assessment of the sensor's output. By means of defined tests and test devices developed for it, a tool is available that in practice has led to good results with the analysis and optimisation of ACC-sensors.

INTRODUCTION

In its first version the ACC-system has been concepted for the use on highways or highway-similar roads, on which the surrounding traffic of the relevant vehicle usually drives in the same direction. All thereby occurring traffic situations in normal traffic belong to the requirements that are demanded of an ACC-System. Whether the ACC can comfortably solve traffic situations appearing at random in reality, is decided by the driver's subjective perception, being individually different depending on the driver.

With this method the system's behaviour in a accidentally occurred situation can only be subjectively judged. However, comparable statements concerning quality can not be made. For a more accurate analysis of the ACC-systems it is therefore sensible to first examine the fundamental reasons. The registration and interpretation of a concrete traffic situation is significantly influenced by the functionality of the distance sensor. Although the vehicle system consists of other components apart from the distance sensor, only the sensor investigation creates the desired basis for an evaluation of the system. Once the performance capability of the sensor is known, the system can be tuned by the remaining components.

The necessity for the development of an objective test method for ACC-sensors, has lead to a co-operation between leading European car manufactures and suppliers and the ika/fka. The goal consisted in developing a tool by which the performance capacity of ACC-sensors can be judged objectively. From this the standard test method for ACC-sensors was developed.

FUNDAMENTAL REQUIREMENTS FOR AN ACC TEST METHOD

One of the main features of the ACC-standard test method is the division of the whole system in the actual distance sensor and in the vehicle's longitudinal control. An evaluation of the whole system, consisting of both subsystems, would always be subjective due to the individual driver's perception and different control strategies of the single vehicle manufactures. By limiting the judgement only to sensors the test method offers the basis for an objective comparison of the performance capability of different distance sensors.

In a large number of traffic situations the ACC-sensor has to guarantee an immaculate function of the system. The boundary conditions of the sensor operation can be summarised by the aspects climate, stretch geometry, and driving state. The sensor delivers the relevant target with distance and relative speed to the vehicle longitudinal controller after the processing of signals.

Since the first generation of ACC-systems is created for the operation on highways and comparable expressways, stretch geometric boundary conditions result from the respective guidelines for road construction. Hereby, also exceptions, such as the entrance into and the drive through a construction site area, have to be taken into consideration, because also in these situation the driver leaves the system switched on. The stretch course can be characterised by the cross-section, the horizontal mapping, contour mapping and the side constructions. Concerning the cross-section an error-free function of the sensor has to be guaranteed in case of one- and multi-lane roads as well as in case of the German standard lane-width of 3.75 m. The same is true for lower widths, for example, at construction sites or abroad, up to lanes that are as narrow as 2 m. In the horizontal and contour mapping the guideline for road construction (RAS-L) in Germany are valid. The driving state of the sensor vehicle is characterised by the speed and the chosen driving lane. The sensor must work without errors in the whole range of the ACC's covered speed. Of course, the operation of the sensor vehicle also has to be possible on any chosen driving lane.

Due to these employment conditions the test boundary conditions were worked out, so that an operation range of the sensors as wide as possible can be tested. The composition of the tests was not only done under the completion point of view, but also under feasibility aspects. The thereby composed tests form the whole test method will be explained in the following.

TEST METHOD

From the large number of traffic situations in which the ACC-sensor had to work without errors, typical situations can be derived (fig. 1). They are chosen in the way that they cover the relevant situations on the one hand, and on the other hand register the characteristic sensor features.

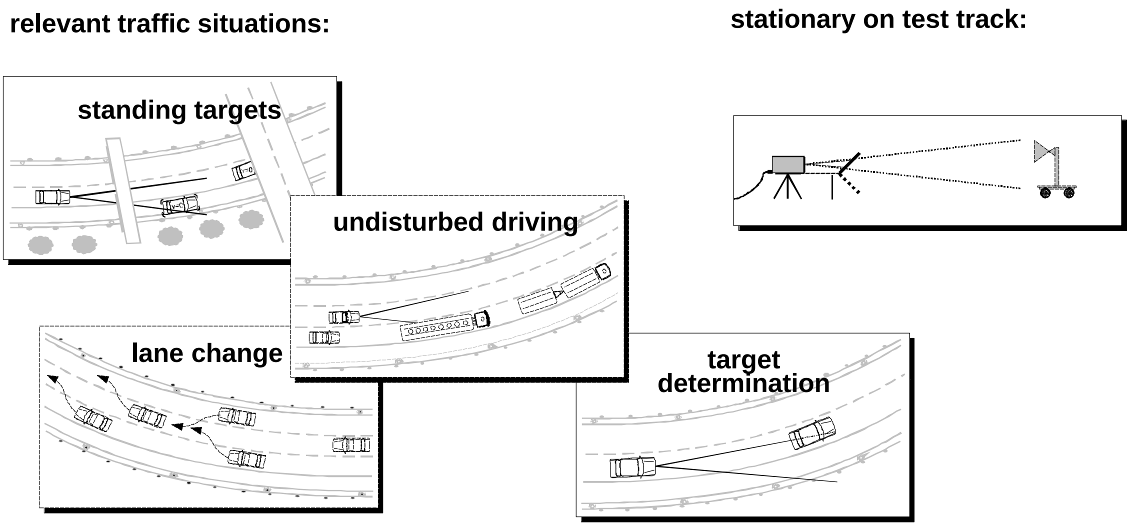

Fig. 1: Typical traffic situations for the ACC operation

The group of standing targets comprises traffic situations that are caused by wrong targets or obstacles. Wrong targets are objects that are positioned outside of the ACC-vehicle's lane, such as, for example standing vehicles at the side of the road, traffic signs or crash barriers. Obstacles are objects that lay within the ACC-vehicle's lane.

Traffic situations of undisturbed driving include the passing of vehicles on the neighbouring lane. They can be subdivided by the positions to each other on the one hand and by the stretch environment on the other hand. The positions concern the lateral place and the order of the target vehicles to each other from the point of view of the ACC-vehicle. By the order of different vehicle classes (commercial vehicles, passenger cars) driving behind or on the side, typical traffic situations can be covered. The stretches are flat straights and curves with a different radius.

Here a further characteristic group of traffic situations is summarised for target determination. Thereby, traffic states are described in which moving targets can be found within the lane of the ACC-vehicle. In this context , for example, it has to be mentioned the approaching of target vehicles and their following. Also here, distinctions concerning stretches, positioning, and combination of different vehicle types can be made.

The lane change of vehicle can be counted to the mostly occurring traffic situations. Hereby, it has to be distinguished between the own lane change and the lane change of others. Furthermore the cut-in and -out in case of different distances and speeds can be investigated.

Further sensor features can be stationarily investigated on a secluded test area. Among them are, for example, the reaction times to an object change, the maximum range in case of different backscatter cross-sections, the sensibility of the receiver, and interference behaviour.

Defined sensor requirements can be derived from the typical operation conditions of the sensors in traffic environment. The goal of the sensor test method is to investigate how well different sensor master the requirements. Thereby, complex traffic situations are divided into single tests that always determine an exactly defined feature of the sensor. Because of this stationary tests on the secluded test area as well as driving tests in realistic traffic environment are executed (fig. 2). By means of defined testing criteria for the sensors now it is possible to analyse the sensor's performance capability.

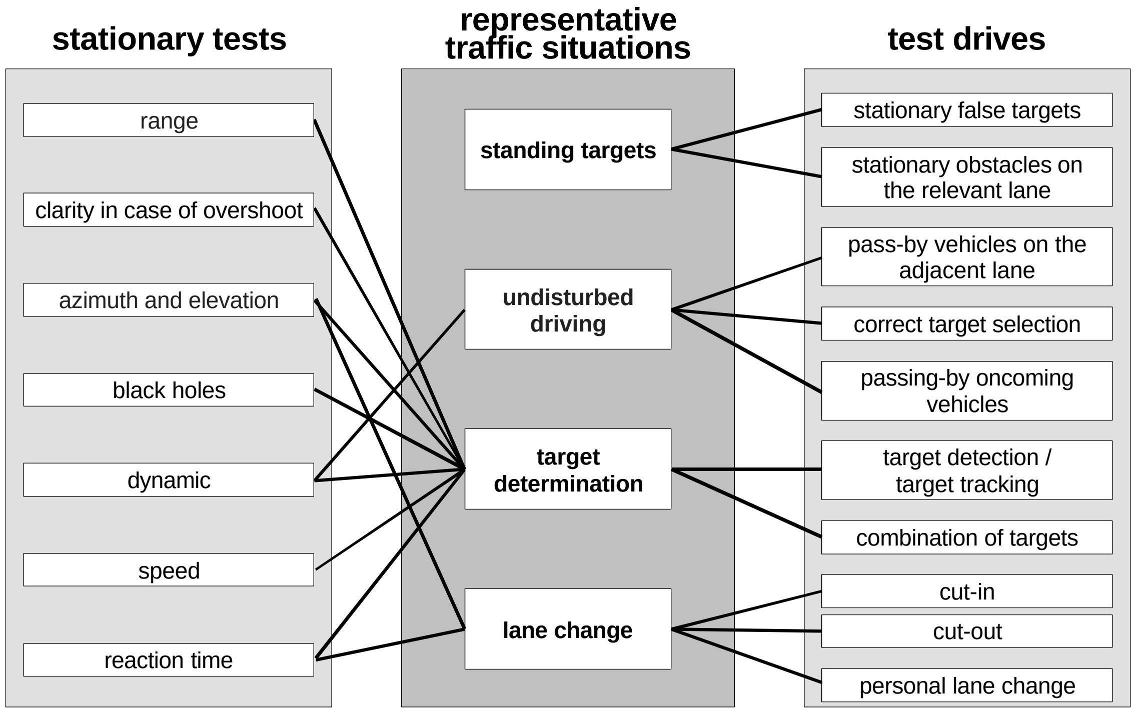

Fig. 2: Test method for sensor evaluation

Every single test is composed of certain preconditions. For instance, exact starting conditions and boundary conditions are fixed for each test. Among them are the driven speeds, distances, and positioning of the participating vehicles to each other. The second step is the exactly determined test procedure, describing the behaviour of the vehicles during the test. Comparable to the script for a film, now every exactly determined traffic scene is reproduced. Variations of the tests such as, for example, a different stretch geometry, help to present even slight differences in the sensors' performance capability. To every driving test belongs the recording of the driving scenes by a video camera. The sensor signals like distance and relative speed of the target object are recorded together with the own speed of the sensor vehicle. The validity of the test is guaranteed by the observance of the test boundary conditions, such as defined weather conditions and keeping defined time periods for certain tests. It is absolutely necessary for the later comparison of the results to strictly observe these limits. By evaluating the valid tests are filtered. Therefore the video of the driving scenes is analysed and the features belonging to this situation, are tested. The data recorded by the measuring computer are partly and automatically evaluated after defined testing criteria.

By means of two examples, it should be briefly presented how the measurements' results can be used for the assessment of the sensor. First of all, in the record in fig. 3 a measurement of the reaction time and the sensor's measurement accuracy is presented. Therefore an objective moving with a defined speed is brought into the sensor's measuring range. Here the actual target speed and the speed detected by the sensor are recorded in a parallel way. The evaluation of the measuring yields the physical values for the defined test criteria.

time [s]	signal [V]	v-sensor [km/h]	v-reference [km/h]	
17.400	-1.572	0.000	36.377	
17.440	-1.489	0.000	36.426	
17.480	-1.499	0.000	36.426	
17.520	-10.000	0.000	36.377	1
17.560	-10.000	0.000	37.402	2
17.600	-10.000	0.000	36.621	3
17.640	-10.000	0.000	33.961	4
17.680	-10.000	0.000	36.719	5
17.720	-10.000	0.000	36.426	6
17.760	-10.000	0.000	36.670	7
17.800	-10.000	0.000	33.594	8
17.840	-10.000	0.000	37.354	9
17.880	-10.000	0.000	36.865	10
17.920	-10.000	0.000	36.670	11
17.960	-10.000	37.584	36.914	1.815
18.000	-10.000	37.692	37.061	1.703
18.120	-10.000	37.800	37.354	1.194
18.160	-10.000	37.800	37.109	1.862
18.200	-10.000	37.872	37.988	0.305
18.240	-10.000	37.980	37.451	1.413
18.280	-10.000	37.980	37.646	0.887
18.320	-10.000	37.980	37.061	2.480
18.400	-10.000	38.052	37.354	1.869
18.440	-10.000	38.160	36.768	3.786
18.480	-10.000	38.160	38.477	0.824
18.520	-10.000	38.160	37.500	
18.560	-10.000	38.160	37.109	
18.600	-10.000	38.232	38.477	
18.680	-10.000	38.232	37.695	1.425
18.720	-10.000	38.232	37.695	1.425
18.760	-10.000	38.232	37.549	1.819
18.800	-10.000	38.340	37.402	2.508
18.840	-10.000	38.340	38.574	0.607
18.880	-10.000	38.340	37.793	1.447
				1.63

target can be seen

reaction time 11 * 40ms = 440ms

target detection

$$\frac{[\,(\text{v-reference}) - (\text{v-sensor})\,]}{\text{v-reference}} * 100$$

absolute error in % over 1 second

speed dissolution = 0.072 km/h

Fig. 3: Evaluation of a stationary test

Another example is the investigation of the lateral solution capability in combination with the lane prediction of the sensor. Here, the test criterion is the drop-in rate and durance in the otherwise object-free distance course. The given test boundary conditions thereby have to be kept exactly. The distance course, the relative speed, the own speed and the curve radius, determined by the vehicle sensor is recorded in this driving (fig. 4). It can be seen that a relevant target is given on the one hand and that also a target change between the two vehicles on the neighbouring lane takes place.

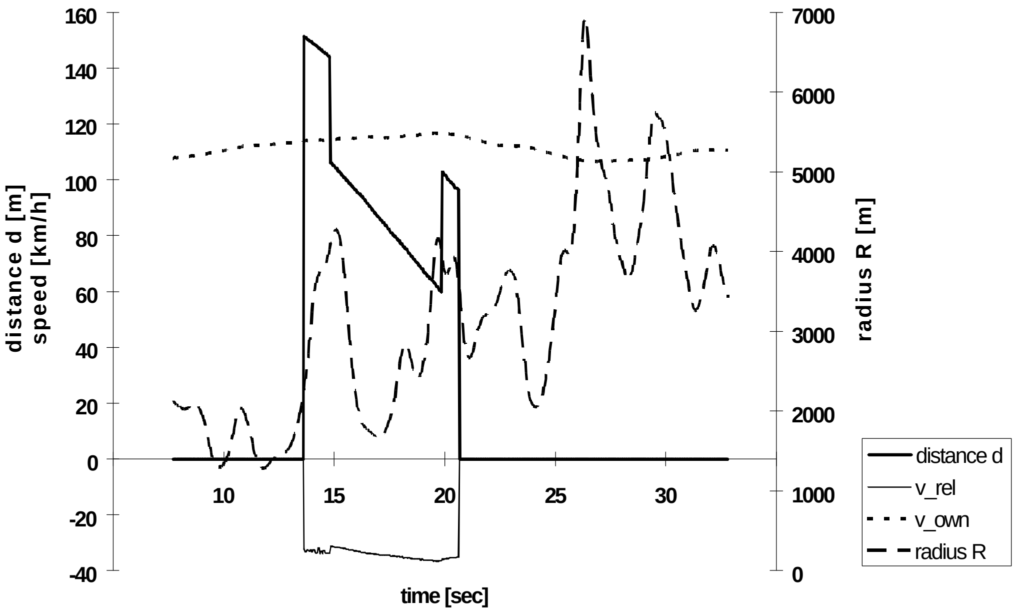

Fig. 4: Measurement recording of a driving test

SENSOR EVALUATION

The main task of the ACC standard test method is the comparison between different sensors and the evaluation concerning their employment aptness. For the sensor test method, a comprehensive test catalogue was determined by considering the operation conditions that guarantees a reproducible test procedure with defined tests. By means of the defined tests, certain basic features of the sensors are tested such as, for example, the range determination, reaction times for target determination or the speed determination of the target vehicles. This is done by driving tests in real traffic environment as well as by stationary tests on a secluded test area.

The quality of a sensor can be determined by its behaviour in the single tests; the evaluation of the single tests is delivered by the physic values of the sensor. By means of a beforehand fixed evaluation scale, points are given for the single test criterions depending on the achieved values. This evaluation scale contains a point distribution for the limit values that sensors of today's generations should achieve. For instance, a target recognition with following follow-up drive is characterised that the occurring drop outs do not exceed a certain percentile period. Is this period exceeded, the sensor receives 0 points for this test. The other value of the scale would be 100 points, signifying in this case a drop-out free distance course. Thus, the physic values of the single tests are converted into points of a homogenous scale.

However, not all of the test criteria are of the same importance. For the above-mentioned case, this can be further explained by the maximum range, the sensor possess at the target recognition. The maximum range can have a larger importance than the drop-out. The relation of the testing criteria to each other in one test, can therefore be individually balanced against each other.

Since furthermore not all sensors are used under the same employment conditions (a commercial vehicle does, f. e. pose different requirements at the sensors than a sports car), a weighting of the tests enables the emphasis of certain tests and the moderation of others in the evaluation depending on the employment purpose. According to the planned employment purpose different weightings, such as, f. e., “free traffic”, “bound traffic” or “commercial vehicle can be set in advance. Of course, also a free weighting of the tests is possible. The thus achieved total points enable a comparison of the sensor performance capability with others sensors available on the market.

REALISATION OF THE TEST METHOD

After having described the test method and the evaluation of the sensors, the question concerning the realisation of the test method remains. The driving tests should be carried out on public roads. On the one hand enough space is therefore available to build up and execute the driving tests, on the other hand also a realistic driving environment is given. Particularly chosen stretch sections enable thus a reproducible execution of the tests.

The execution of tests on public roads, of course, also leads to problems. The surrounding traffic would unnecessarily make the observance of the given test boundary conditions more difficult and in case of a few driving manoeuvres even represent a severe danger. Therefore the vehicle column, actually participating in the test, is always accompanied by an additional vehicle. This keeps the following traffic back for the period of one test and sees to it that other vehicles cannot drive into the test range. Additionally, all vehicles are connected by radio, enabling an easy co-ordination of the tests. With the own big vehicle park even complex driving situations can always be reproducibly presented, because there are always the same vehicles available for the tests.

The stationary tests are carried out on the institute’s own test track. For this purpose, special test devices were developed. The influence of temperature on the sensor capability is, f. e. determined by a special climate box. The sensor is hereby adjusted to the take-out front of the box in such a way that he flush-fittingly sits in the box. The sensor can thereby be mounted in different heights between approx. 35 cm and 100 cm. The inner box can now be brought to the right temperature by a suitable heating or cooling system. The temperature level can be varied between –25°C and +85°C.

For the determination of reaction and system times of the sensor until the recognition respectively correct output of a target object, a special snapping mechanism was developed. For the determination of these features it was necessary to bring the target object in no time into respectively out of the sensor’s sight. Regardless the sensor geometry the target should thereby appear in the middle of the sensor rays, so that the influences of the ray geometry or lane prediction are omitted. Therefore it was necessary to place the targets within the sensor registration range before the measuring and to deviate the sensor ray by means of a mirror.

The snapping lock now allows the sudden interruption and release of the sensor’s course of rays to the target without influencing the transmitting or receiving part. Therefore a mirror is installed into the ray course of the sensor that mirrors all the transmitted waves of the sensors up and away. For the swift movement of the mirrors a mechanical spring is used. The opening time is less than 20 ms.

CONCLUSION

The described standard test method offers the possibility to assess ACC sensors concerning their performance features in driving operation as well as in stationary ones. For this purpose the test method contains exactly defined tests that on the one hand are carried out in real traffic and on the other hand on the institute's own test area. This method has proofed to be the suitable tool for the investigation and further development of ACC-sensors.

Based on the requirement to develop an easily handable ACC-sensor evaluation method the tests were derived from relevant traffic situations by order of several leading car manufacturers and automotive suppliers. The focal point of the investigations therefore clearly lays on the practical feasibility of realistic driving tests. It turned out that a large number of tests is necessary for a comprehensive evaluation of ACC-sensors. Although the time expense for the execution of the tests is rather high, it can still be minimised by a sensible distribution. In order to ensure the test validity, certain requirements such as starting conditions and test procedure have to be kept strictly.

By means of different weightings of the single tests, the performance of the ACC-sensors can be interpreted under various points of view. This makes the evaluation of a sensor easier against the background of the later employment purpose.

After multiple applications the here described method has presented itself as a suitable tool for the sensor evaluation and further development. In the meantime the method has turned into a sort of standard method for the evaluation of sensor performance capability. The flexible structure of the test method makes also possible the assessment of new sensor concepts. It is also possible to always improve the method in order to examine additional requirements of the sensors. Like this test procedures for urban traffic or bad weather conditions are on the development stage.