A Methodical Framework for the Design of Multi-Sensor Systems in Automotive Applications

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Abstract *Modern cars comprise various driver assistance applications which depend on reliable surveillance of the vehicle's environment. Therefore, sensors known from aviation and military – like radar or laser – are combined to multi-sensor systems and employed to provide specific observation data. The actual choice of the single sensors depends on the scope of the application and in turn has a considerable impact on the overall system performance. We investigate multi-sensor systems composed of different sensor technologies and provide a methodical framework for the design of sensor based applications and the evaluation of a multi-sensor system regarding specific application requirements. We use both sensor and application characteristics to model the system and propose a metric that supports basic design decisions and assessment of alternative sensor systems at an early stage of system development. The presented approach is very flexible and could be used for any application that relies on multi-sensor systems.*

Keywords: *System Design, Modeling, Sensors, Automotive, Driver Assistance, Dependability.*

1 Introduction

All major car manufacturers make remarkable development efforts to increase the electronic abilities of modern cars in driver assistance, collision avoidance or crash mitigation.

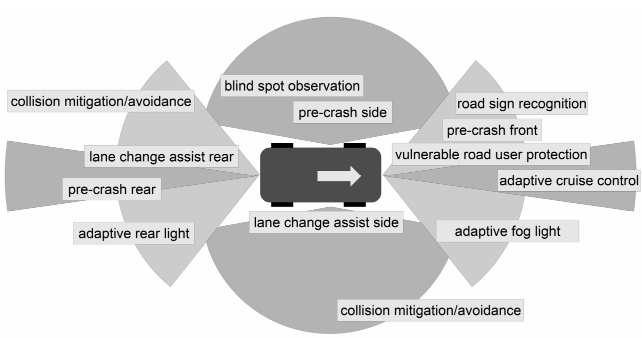

Figure 1: Sensor based ADAS functions

The various applications are often summarized as Advanced Driver Assistance Systems (ADAS), figure 1 shows some actual implementations. They depend on a potentially high number of sensors with different coverage areas, accuracies, kinds of perceived parameters and deployment or design constraints. The available sensor technologies vary from radar to laser, vision based or ultrasound devices, each one providing certain projecting abilities or specific limitations. Hence, the combination of single sensors towards a multi-sensor system is a crucial aspect of the ADAS design because it defines the input of the signal processing chain and therefore the maximum possible quality of context perception. Especially for applications engaging in the braking system or deploying irreversible restraint devices, sensor failures in terms of mistaken scene interpretation or insufficient detection performance mark serious threats for both occupants and other road users. In cooperation with the German car manufacturer Audi we investigate multi-sensor systems with respect to various ADAS requirements. One common approach for such investigations on sensor devices is to install real hardware into test cars and to work off a list of predefined test scenarios, which is expensive in terms of hardware, time and manpower, not guaranteeing that all shortcomings of the multi-sensor system could be revealed. However, previous investigations mainly focused on improvement and test of real hardware devices without providing a compact and flexible analytical evaluation method as we propose it. In [1], [2] the technical capabilities of radar are enhanced and simulations and test runs are performed. [3] propose replacement of radar by video devices for certain application areas. [4] evaluate the dependability of an ADAS application, yet restricted to aspects of in-car communication timing, task scheduling and reliability. In [5] an improved simulation concept for radar devices is presented, specific demands of ADAS applications are not considered. Additionally, there have been various research activities concerning the configuration of multi-sensor systems. [6] call for an architecture consisting of a 77 GHz long range radar and a laser sensor to cover low and medium range areas, [7] from Delphi Automotive Systems combine radar and lidar sensors to make use of the advantages of each technology. To emulate a scanning-link effect, [8] describe the use of three narrow beam radar sensors which are activated one after

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another. [9]–[12] integrated heterogeneous sensor systems – radar, laser and video – into a highly flexible system and in [13]–[15] radar and lidar sensors detect potential obstacles. A video sensor device is then used to confirm or reject the object hypotheses. Taking into account these previous efforts from scientific research and industry, the methodical framework that we propose represents a novel approach for multi-sensor system evaluation in automotive environments. We provide an analytical sensor selection technique which is applicable at an early stage of system development. It allows for modeling both sensor dependent factors like range, field-of-view (FOV) or sensor resolution and application specific timing or coverage requirements. Thus, various multi-sensor system configurations can easily be compared in order to obtain an optimum basic system design decision. The paper is organized as follows: In section 2, a brief survey on radar and lidar technology is given. Section 3 presents sensor device specific performance measures, whereas in section 4 the sensor independent, thus application specific factors are defined. Taking into account these findings, section 5 introduces a metric for the overall sensor selection potential. To emphasize the applicability of our approach and the significance of the outcomes, section 6 offers a detailed evaluation of an exemplary ADAS scenario. Finally, section 7 summarizes the achieved results and provides an outlook on future work on this topic.

2 Sensor technologies

Various technologies are available for multi-sensor systems in automotive environments. In the present work, we investigate radar and lidar sensors and in this section, we provide a brief overview on the technological peculiarities. A more comprehensive survey on the respective technologies can be found in the referenced literature.

2.1 Radar

Radar (Radio detection and ranging) sensors have been extensively used in military and aviation environments and have proven to be particularly suitable for issues of object detection. Although the adoption of radar technology into automotive applications brings some challenges, e.g. due to the smaller area of operation the exact location of the object has to be measured with a much higher accuracy, there are advantages which make this sensor technology very promising. These advantages include the intrinsic capability of radar of measuring the relative velocity of an object, using the Doppler shift. Another unique property is the robustness against bad weather conditions like heavy rainfall and fog [9]. Currently there are two frequencies that are being used for automotive radar sensors. The higher frequency of 76–77 GHz is used for long range radar (LRR) with up to 150 m detection range [6]–[8]. The sensor's FOV is usually narrower than the FOV of the 24 GHz short range radar (SRR) sensors. One drawback of radar sensors is that detection of an object requires reflection of the radar signal at the edges of objects, thus additional environmental information, e.g. from lane markings, can not be considered. Table 1 summarizes some properties of radar devices. The FOV value refers to the complete device FOV and not to a single beam FOV. The opening angle of a single radar beam within a multi-radar system is 1–44°.

Table 1: Radar sensor properties

Property	Value/Method
Range	20–50 m (SRR) / 100–150 m (LRR)
FOV	20–60° (SRR) / 5–8° (LRR)
Object Detection	Reflection center may differ
Relative Velocity	Intrinsic via Doppler shift

2.2 Lidar

Lidar (Light detection and ranging) technology is based on emission and reception of laser beams. Like radar it is capable of detecting the position of an object depending on a reflected signal, whereas the restriction that radar signals are only reflected at the edges of an object does not apply for lidar signals. This gives lidar the ability to measure the geometric parameters of a detected object very accurately [16], [17]. Furthermore, lidar devices are cheaper and smaller than radar systems [8]. The main drawback of lidar systems is the decreasing performance under bad weather conditions. Especially the influence of rainfall, fog or dirt can make the sensor almost blind [8], [16]. With a missing direct way of measuring the relative velocity of an object, a lidar system has to track its movement over a certain period of time. This marks an additional amount of computational and communication load in comparison to radar signal processing [7]. Current lidar sensors are either scanning the environment which means a single beam moves mechanically or optically, or multiple stationary sensors produce multiple beams and cover the FOV collaboratively. Depending on the mechanical design (scanner, multi-beam) the lidar FOV can cover every desired area up to 360° with a range of up to 120 m [16]. Table 2 summarizes some properties of lidar sensor devices. Again, the FOV value represents the coverage of the whole multi-beam sensor or scanner FOV. Compared to radar, the laser beams have a narrower width of 1–3°, providing better lateral positioning.

Table 2: Lidar sensor properties

Property	Value/Method
Range	70–120 m
FOV	5–30° (multi) / 360° (scan)
Object Detection	Extremely accurate
Relative Velocity	Via object tracking

3 Spatial coverage and resolution

The overall performance of an ADAS application is influenced by many factors, e.g. the application implementation on the uppermost layer, the communication performance, the efficiency of sensor data fusion, the quality of input data or the configuration of the multi-sensor system. The performance or dependability of an ADAS application is typically measured in detection and tracking accuracy or false detection rate. In order to provide a low level metric for sensor selection potential, this section introduces some general sensor characteristics and some technology specific parameters. Evaluating each sensor technology according to the introduced metrics helps to find coverage leaks or alternative systems. The interesting properties to compare the sensor selection on a low level of abstraction are range, field-of-view and sensor accuracy. Obviously, no sensor specific properties like weather robustness or visual interpretation of the environment are considered. However, the integration of these values is possible and could result in a multidimensional interpretation of the application specific area of interest. Table 3 provides an overview of characteristic resolution values for radar and lidar sensor technology.

Table 3: Sensor resolutions (from [18])

Device	Angular (α)	Range (d)	Rel. Velocity (v)
LRR	0.5°	1 m	0.3 m/s
SRR	0.1°	0.1 m	0.5 m/s
Lidar	0.05°	0.1 m	1 m/s

3.1 Sensor range limitations

The range of a sensor has a strong impact on the coverage area. Modeling of the range limitation and in turn the detection performance can be expressed by the following equation:

$$d(x) = \begin{cases} 1 & x \le range \\ 0 & else \end{cases} \qquad (1)$$

A vendor commonly specifies a sensor with an operational range (cf. tables 1 and 2), depending for example on the adjusted transmitting power and azimuth angle. An accurately working sensor device should be able to keep its full detection performance as long as an object is within this range. Reliable detection of objects in greater distances than the range can not be guaranteed, thus we assume that the specified range is a hard upper limit, i.e. we do not consider an additional gray area afterward with somehow decreasing detection ability.

3.2 Field-of-view limitations

Modeling the FOV limitations can be achieved similarly straightforward. The area of interest of a certain ADAS application can be modeled by a function *g(x)* and the FOV of the sensor by a function *f(x)*, respectively. For many ADAS scenarios that depend on surveillance of parts of the environment around the ego-vehicle[1], the area of interest can be modeled by a simple line equation which models half of this area. This leads to the same coverage fraction as with a complete model as long as the beam shapes are symmetric and centered:

$$g(x) = mx + t \qquad (2)$$

Depending on application requirements the area of interest covers the whole front, side or rear side of the vehicle (t: half initial width of the overall area) and increases its width according to m. The FOV of the sensor can be derived from line equations or directly by using the sensor specific azimuth angle α_{az}. Since only half of the area of interest is modeled, α_{az} is divided by 2:

$$f(x) = x \tan \frac{\alpha_{az}}{2} \qquad (3)$$

We introduce equation 4 to model the ratio between sensor FOV and coverage area, i.e. which fraction of the required observation area the sensor is effectively able to cover:

$$a(x) = \min\left(1, \frac{f(x)}{g(x)}\right) \qquad (4)$$

Figure 2 depicts a sample sensor FOV in a specific ADAS scenario. The sensor has an azimuth angle α_{az} of 12°. The area of interest for the ADAS application is defined as the corridor in front of the car with a reasonable increase in its width (e.g. width of 14.4 m at range 100 m).

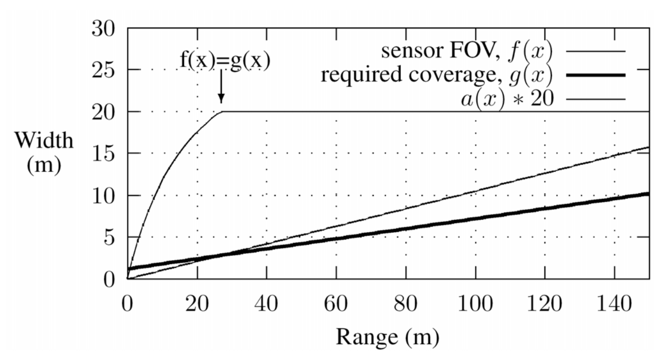

Figure 2 : Sensor FOV and required ADAS coverage

The sensor does not cover the whole area of interest in the region close to the front end of the vehicle. Note that the efficiency function *a(x)* has been scaled by the factor 20. Otherwise, the curve of *a(x)* would hardly be visible due to the different order of magnitude compared to the other graphs in the plot.

[1] The *ego-vehicle* is the vehicle where the multi-sensor system is installed.

3.3 Sensor resolution

Different sensors have different horizontal and vertical accuracy and resolution (cf. table 3). Whether the sensor accuracy in terms of horizontal, distance and relative velocity resolution is sufficient for the demands of a specific ADAS application can be estimated by dividing the average resolution by the maximum (or reference) value of the regarded parameter. We propose equation 5 to reflect that coarser values of sensor resolution and accuracy might lead to a decreasing suitability of the sensor device for a certain ADAS application:

$$e(\alpha, d, v) = \left(1 - \frac{\alpha}{\alpha_{\max}}\right) \cdot \left(1 - \frac{d}{d_{ref}}\right) \cdot \left(1 - \frac{v}{v_{\max}}\right) \quad (5)$$

Equation 5 covers the demands of applications that rely on angular, distance and velocity resolution. However, applications with a focus on only one or two of these performance values can easily be modeled by setting $\alpha = 0$, $d = 0$ or $v = 0$, respectively. The parameter α_{max} depicts the maximum required observation area, d_{ref} is the reference observation distance, i.e. the minimum distance to a detected object at which the application can deploy full functionality and v_{max} denotes the maximum relative velocity for which the ADAS application is designed. Scaling the sensor parameters α, d and v with these values yields a relative accuracy of the device with respect to the application requirements. For example, a sensor with an angular resolution of $\alpha = 15°$ is ill-suited for a narrow-beam application that requires a very accurate positioning, whereas the same device can probably be employed for an application which requires roughly sectioned data, e.g. the distinction between environment in front or on the side of the vehicle. The overall accuracy of one sensor within the multi-sensor system is calculated as the product of the individual values instead of computing a mean value. The intention is to highlight the correlation of a sound sensor performance in each of the categories (angular, distance and velocity resolution) and the overall performance or suitability of the device. Considering equation 5 for a certain ADAS application, a sensor might exhibit a good scaled distance and relative velocity resolution, e.g. yielding values of 0.94 and 0.98 for the respective terms. However, in case the angular resolution is very imprecise, e.g. figured out to be 0.21, the sensor will hardly satisfy the demands of a dependable ADAS application. Determining the mean value of the single accuracies yields $(0.94 + 0.98 + 0.21) \cdot ⅓ = 0.71$, whereas calculating the product adds up to $(0.94 \cdot 0.98 \cdot 0.21) = 0.19$. The product of the single resolution accuracies makes the shortcomings of the device much more obvious than the mean value estimation. At this stage of the approach, we do not consider other sensor specific factors that might influence the accuracy, like placement, temperature or acquisition frequency.

4 Timeliness of object detection

In the last section various factors which influence the accuracy of a specific sensor in a multi-sensor system for a given ADAS scenario were introduced. The efficiency of the overall system is also affected by sensor independent parameters. For example, SRR sensors with high FOV may be inappropriate for an application that provides collision avoidance for high velocity. Depending on the demands of the application, equation 6 expresses the usefulness of the sensor information on detected objects:

$$o(x) = \begin{cases} s(x) & x \le d_{rel} \\ t(x) & else \end{cases} \quad (6)$$

The function $t(x)$ evaluates the usefulness of the sensor data in case it is acquired in time and the object is still separated from the ego-vehicle sufficiently. The usefulness of the sensor data is decreasing according to $s(x)$ if the object is too close for the ADAS application to impose its full functionality in time, i.e. the detected object is closer to the ego-vehicle than the relevant observation distance d_{rel}. The actual steepness of $s(x)$ depends on the sensor based application. In some cases sensor data about objects at closer distances than d_{rel} will be discarded rigorously, e.g. $s(x)$ is a step function switching between 0 and 1, while other applications decrease more smoothly in efficiency, for example by a linear function $s(x)$.

5 The $\xi(x)$-function

The $\xi(x)$-function serves to combine sensor coverage performance, sensor accuracy and usefulness of the sensor data. It therefore represents a metric for the overall sensor selection potential. The usefulness, as expressed by $o(x)$, marks the requirements of the ADAS application. Based on this, we consider the sensor performance and compute to which extent the multi-sensor system is capable of fulfilling these specific ADAS requirements. The definition of the $\xi(x)$-function is shown in equation 7:

$$\xi(x) = o(x) \cdot e(\alpha, d, v) \cdot a(x) \cdot d(x) \quad (7)$$

The $\xi(x)$-function for the combination of n sensors is defined by the maximum of the individual sensor accuracy at a specific point:

$$\xi(x) = \max\left(\xi_1(x), \xi_2(x), \ldots, \xi_n(x)\right) \quad (8)$$

This combination is valid for non-complementary sensor layouts. Complementary sensors are assumed to collaborate when observing the vehicle's environment, e.g. one radar installed in the right side of the bumper and one in the left side, each one covering about one half of the area in front of the car, thus complementing one another for observation of the whole front. The maximum function for such a multi-sensor system would still produce an overoptimistic 50% overall coverage, hence a more complex combination method by an advanced *ξ(x)*-function would be needed. Throughout the rest of this paper, we use the *ξ(x)*-function as defined in equations 7 and 8. The relationship of *ξ(x)* to *o(x)* describes the sensor performance, since *e(α,d,v)*, *a(x)* and *d(x)* are device specific values. Introducing a certain threshold t as a lower bound for acceptable performance, we can define a *fail(x)*-function according to equation 9:

$$fail(x) = \begin{cases} 1 & \dfrac{\xi(x)}{o(x)} = e(\alpha,d,v)\cdot a(x)\cdot d(x) \le t \\ 0 & else \end{cases} \quad (9)$$

The actual setting of $t \in [0; 1]$ depends on the ADAS application. In general, the more significant the effect of the application, the closer tends t to 1, resembling the increased performance requirements. Areas with insufficient sensor capability are detected in case the sensor performance decreases below t, indicated by $fail(x) = 1$.

6 Example

The following example gives an overview of the possibilities of the proposed approach for the sensor selection metric. We assume an ADAS application for Autonomous Emergency Braking (AEB), where the lane in front of the ego-vehicle is observed. In case an object is detected and the ego-vehicle is on collision course without any driver reaction, the system will automatically trigger a full brake application to avoid the impact. We consider a scenario with a maximum ego-vehicle velocity of 90 km/h (25 m/s) and investigate the dependability of four different multi-sensor systems, using SRR, LRR and lidar sensors (all employed in the midsection of the front end) as specified in section 2. To determine the overall sensor resolution performance, we set the maximum relative velocity to 25 m/s and $\alpha_{max} = 180°$, as the AEB ADAS application reacts only to objects in front of the ego-vehicle. We restrict the scope of the application to detection of objects driving in the same direction as the ego-vehicle. Thus, the maximum relative velocity can not exceed the velocity of the ego-vehicle, reaching it in case the ego-vehicle is on collision course with a fixed object with velocity $v = 0\ km/h$.

As the ADAS function triggers a full brake application, the relevant distance d_{rel} must be related to the braking distance, calculated according to $d_{braking} = v^2/2a$, where v is the velocity of the ego-vehicle and $a = 9.81\ m/s^2$ is set to the constant of acceleration due to gravity. If we assume a data processing delay (from sensor over bus systems and electronic control units to final actuator, i.e. braking shoe and disk) of $t = 300\ ms$, we must consider the additional distance $d_{add} = t \cdot v$ the car moves with the given velocity within this time until the application can employ full functionality. With $d_{rel} = d_{braking} + d_{add}$ the overall application relevant observation distance emerges to be 39.35 m. Including range and resolution parameters of the sensors, we can now determine the actual performance values of the sensors as shown in table 4.

Table 4: Sensor parameters and performance estimation

	SRR	LRR	Lidar
Range FOV	20–50 m 20–60°	100–150 m 5–8°	70–120 m 5–30° (multi) 360° (scan)
Resol. α Resol. d Resol. v	0.1° 0.1 m 0.5 m/s	0.5° 1 m 0.3 m/s	0.05° 0.1 m 1 m/s
$1-\frac{\alpha}{180°}$	0.99944	0.99722	0.99972
$1-\frac{d}{39.35m}$	0.99745	0.97458	0.99745
$1-\frac{v}{25m/s}$	0.98	0.96	0.988
$e(\alpha,d,v)$	0.97696	0.96021	0.95729

The usefulness of sensor data is expressed by equation 6:

$$o(x) = \begin{cases} \dfrac{x}{39.35} & x \le 39.35 \\ 1 & else \end{cases}$$

Recalling the application area – autonomous braking – it appears to be reasonable that the efficiency of the ADAS function decreases as the distance to a detected object diminishes. The linear descent reflects that a braking intervention based on sensor data is possible up to very close distances, however less efficient in terms of reducing velocity prior to a potential collision. Applying equation 2, a meaningful choice for the application relevant area of interest can be defined as:

$$g(x) = 0.06x + 1.2$$

The offset t in the line equation is chosen such that the initial width of the relevant area, i.e. the maximum width of the vehicle's front end, is resembled by $t = 1.2$. The slope factor $m = 0.06$ yields a lateral extension of 7.12 m at the application relevant distance of 39.35 m, which seems to be sufficient for surveillance of the lanes in front of the car. Finally, we have to set the threshold t for the failure function *fail(x)*. This parameter has to be adjusted intuitively by the system designer, depending on the effect of the actual application. Safety critical ADAS functions require a higher level of sensor performance (t closer to 1) than applications that are solely serving driving comfort. For the AEB ADAS application, we set $t = 0.86$ and estimate the performance of the various sensor sets according to equation 9.

6.1 Multi-sensor system 1 – SRR/Lidar

The system consists of one short range radar and an additional lidar sensor. The combination of different physical measurement techniques enhances the detection potential of the system, yet with the drawback of weather sensitivity of the lidar device. Figure 3 presents the curves for the sensor selection potential $\xi(x)$, the predefined usefulness of the sensor data $o(x)$ and the failure function $fail(x)$, respectively. The actual range and FOV settings of the sensors are denoted in the caption of each sub-figure. Plot a) shows insufficient surveillance of the first few meters by both sensors, leading to $fail(x) = 1$. Afterward the SRR rapidly covers the area close to the front end of the vehicle, resulting in an almost optimal coverage. However, for distances above 30 m the SRR detection performance drops to zero, while the narrow beam width of the lidar sensor does not provide sufficient coverage yet. Beyond 42 m, the coverage area of the lidar sensor is satisfactory through to the lidar range of 120 m. As one can easily see from plot a), the dependability requirements of the AEB ADAS application will not be met without a touching up of the sensor settings. This is done by increasing the range of the SRR and the angle of beam for both the SRR and the lidar sensor. The effects are illustrated in plot b), namely an improved performance of the multi-sensor system for both the area close to the ego-vehicle and especially around the application relevant distance d_{rel}.

6.2 Multi-sensor system 2 – SRR/LRR

In sensor system 2, solely radar technology is employed. The configuration of the sensors as shown in plot a) of figure 4 yields an absolutely unsatisfying performance for the corpus of the explored range. Trying to overcome these shortcomings, we set the angular and range parameters of both the SRR and the LRR to the upper limits (cf. table 1). However, there remains an area from about 50 m to 70 m with poor sensor set performance as obvious from plot b). A possible solution might be to install two LRR devices with a horizontal displacement and thus to increase the overall LRR coverage area by complementary radar beams. Of course, this implicates additional efforts in terms of design, construction and calibration of the collaborating radar sensors. However, employing one SRR and a single LRR we can state that the specific requirements of the ADAS application will hardly be fulfilled.

6.3 Multi-sensor system 3 – Lidar(scan)/LRR

Sensor system 3 is composed of a lidar device scanning the environment by a moving single beam and a competitive LRR sensor. With a scanning radius of 180° the lidar sensor is able to cover the whole front end of the vehicle, while the LRR is capable of detecting objects in larger distances. Plot a) of figure 5 highlights the sound performance of the sensor set for all distances up to about 70 m. Further enhancement can be achieved by increasing the LRR beam width from 5° to 8° as shown in plot b). The LRR range of 150 m is covered with a sufficient performance which makes this sensor set very promising for the AEB ADAS application.

6.4 Multi-sensor system 4 – Lidar/LRR

The fourth combination of sensor devices is a system of one multi-beam lidar sensor and an LRR. Even though the same basic technology is employed as in sensor system 3, the sensor selection potential of sensor system 4 shows a quite contrary behavior in plot a) of figure 6 compared to plot a) in figure 5. The range of the fixed lidar device is significantly larger than the range of the lidar scanner, yet the adjusted beam width is extensively smaller, which leads to an insufficient performance for distances up to 70 m. Adjusting both sensors to the upper limits according to tables 1 and 2 we obtain a considerably better performance and suitability for the actual ADAS application. Except for the area close to the ego-vehicle, the sensor selection potential is almost the same as with a scanning lidar device in sensor system 3.

7 Conclusions and Future Work

In this paper a methodical and straightforward approach for sensor selection in multi-sensor systems for automotive applications is proposed. Various influences on the performance of a single sensor as well as sensor specific parameters are considered in order to provide a detailed evaluation of a sensor system’s performance. The regarded influences are sensor range, field-of-view and sensor accuracy. The modeling elements we introduce are both intuitive and easy to adapt to actual requirements or constraints in design of multi-sensor system of systems. Based on the results of the evaluation, system designers are provided with a sound ability to detect weaknesses in coverage quality or to highlight alternative sensor settings or system configurations. Taking into account both general sensor characteristics and specific coverage, resolution or timing requirements, the approach is very flexible and can be applied to numerous application fields besides automotive multi-sensor systems, e.g. avionics, robotics or military domains like missile defense or echolocation. Next, we will refine the approach by investigation of further sensor technologies, especially video sensors. Integrating vision based devices is challenging as they are commonly employed to verify object hypotheses from active sensors like radar or lidar without providing actively measured detection values. For instance, we have to find a metric that maps the pixel-based scene perception of a video sensor onto the distance and angular object data from active sensors’ measurements, yielding a common spatial cognition of the vehicle’s environment. In addition, we want to model sensor specific abilities of all considered technologies, e.g. regarding weather conditions or asymmetric sensor deployment. Additional enhancement is possible in terms of automatic multi-sensor system exploration. Applications, performance requirements, design restrictions and many other kinds of parameters can be modeled and optimized sensor selections can be created automatically using huge sensor databases.

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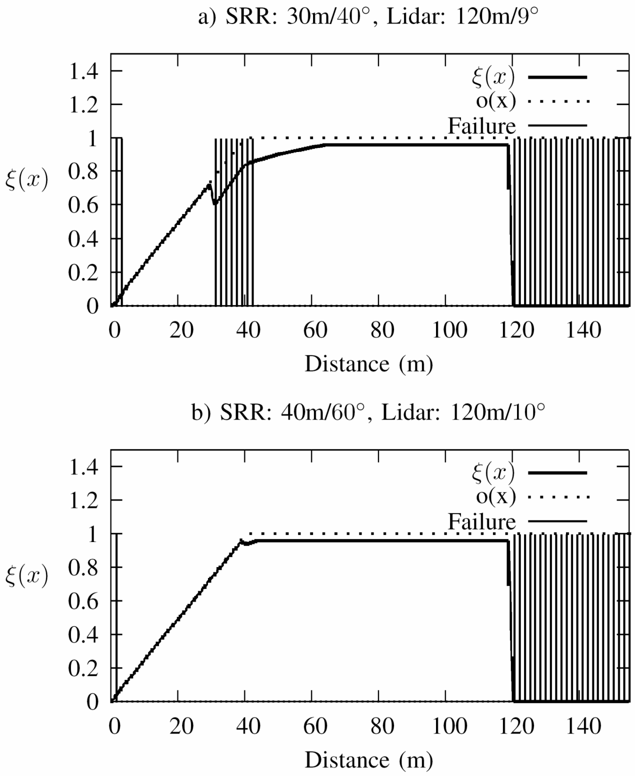

Figure 3: Multi-sensor system 1 for ADAS application

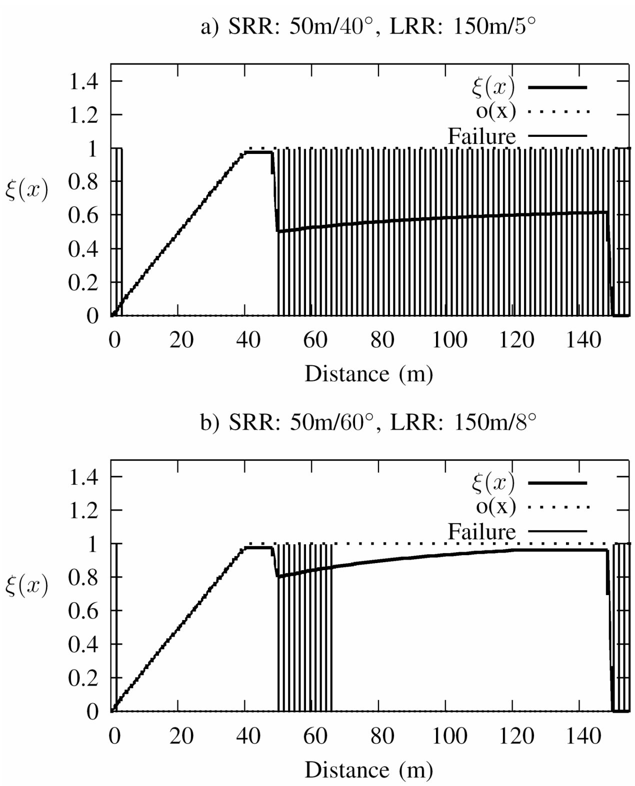

Figure 4: Multi-sensor system 2 for ADAS application

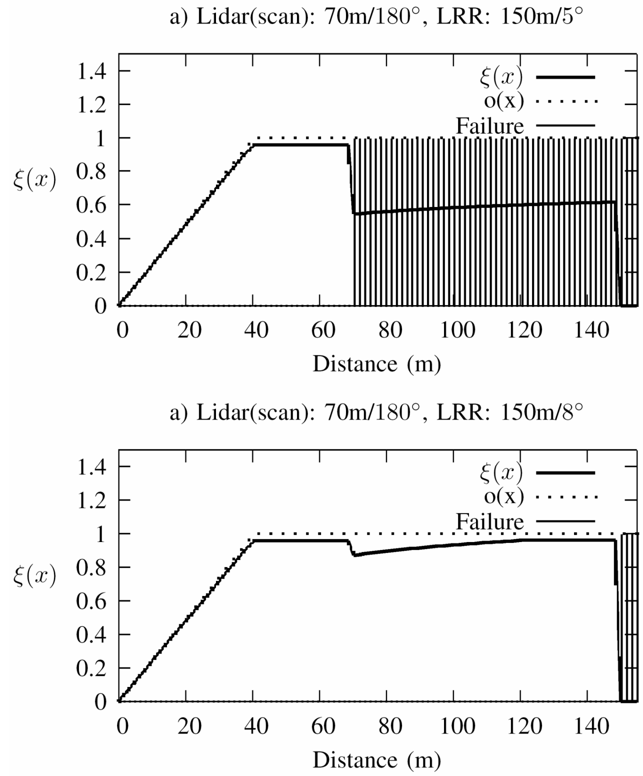

Figure 5: Multi-sensor system 3 for ADAS application

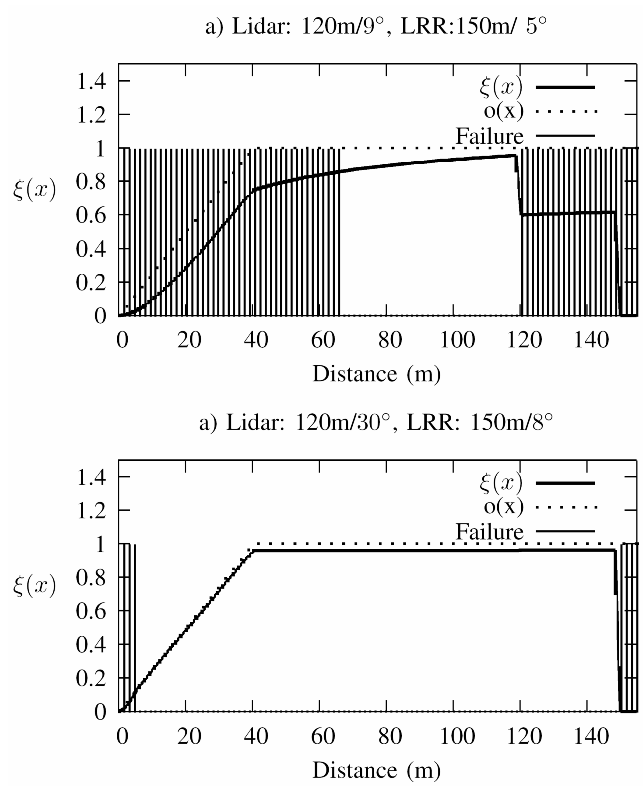

Figure 6: Multi-sensor system 4 for ADAS application