

**ATZ** extra

When machines learn to see:  
automating mobile machines in  
changeable environmental conditions

## **Offprint**

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# Reliable Object Detection for Autonomous Mobile Machines

Failsafe detection of people and objects in changeable weather and environmental conditions presents major challenges for manufacturers of autonomous mobile machines. The DIN EN 62998 draft standard for safety-related sensors designated for outdoor use is long on guidance, but short on specific procedural instructions. ITK Engineering presents an approach that looks at processes earmarked for automation as a whole. It spells out the specifics of developing and validating reliable object detection devices in compliance with the regulations of the DIN EN 62998 standard.

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## MOTIVATION

Safeguards for preventing accidents and injuries caused by industrial driverless transport vehicles usually come in the form of tactile or electro-sensitive safety devices. Varying weather and challenging environmental conditions are to be expected outdoors, hence systems developed for indoor use are unfit for this purpose. To enable autonomous machines to be used outdoors, the DIN EN 62998 standard defines how a sensor's properties are to be assessed while taking environmental influences into account. It does not, however, give specific instructions. This article spells out the procedure defined by DIN EN 62998 in concrete terms and describes how to follow this procedure in a holistic development process with custom simulations to support the development process.

## DEVELOPING A METHOD FOR RELIABLE OBJECT DETECTION DEVICES

The following section outlines ITK Engineering's approach for specifying and implementing the generic requirements of DIN EN 62998, while factoring the application-specific requirements for this type of system into the design equation,

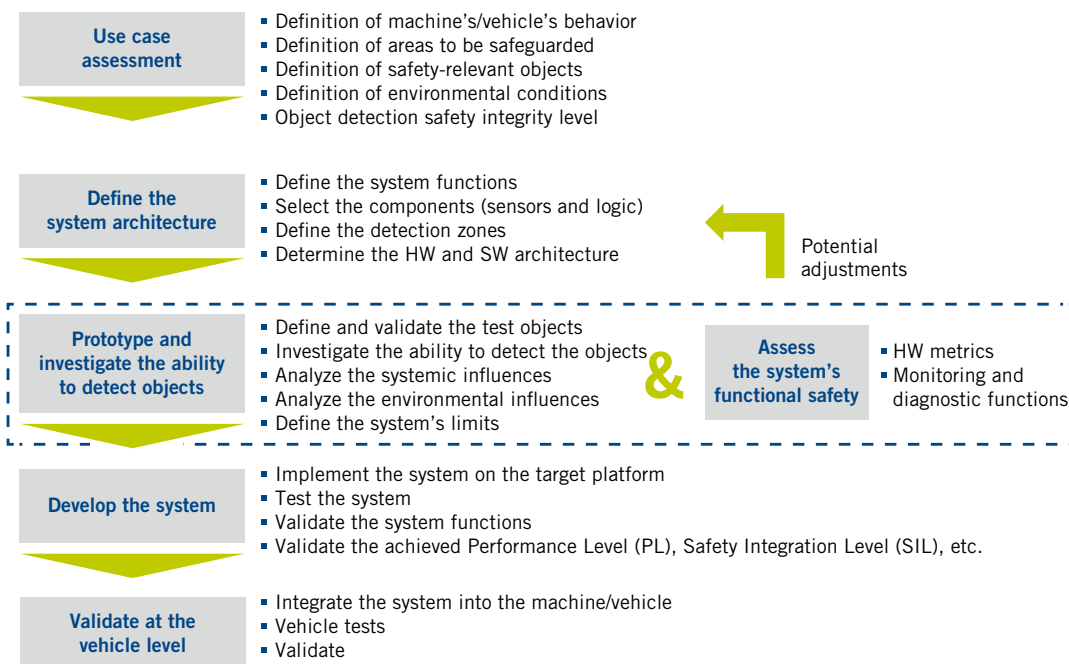
**FIGURE 1.** The first step is to analyze the use case in order to identify the requirements for the object detection device. This step is crucial for the entire development process. Engineers must first define the areas to be safeguarded and safety-relevant objects before they can begin selecting the necessary sensor technologies. For example, ultrasonic sensors alone fall short of the requirements for detecting objects at great distances. The surrounding conditions also have to be taken into consideration when preselecting sensors. LiDAR (Light Detection And Ranging) sensors are ineffective in very dusty environments, thus another technology is better suited for this use case. Uneven surfaces, commonplace in off-highway applications, also make it difficult to choose the right sensor technology. A hazard analysis and risk assessment serve to determine the safety integrity level of the object recognition device, which will have to be validated as the final step of this development process.

The second step is devoted to defining the system architecture, building a prototype, and investigating the detection capabilities of the proposed object detection device. This step could entail iterations: The architecture may have to be adapted as this investigation sheds light on the technology's ability to

detect objects or reveals systematic and environmental influences that require its adjustment. At this stage, engineers also have to consider the functional safety of the object detection device with the applied functional safety standard(s) in mind. As soon as the system's ability to detect objects is established and the environmental influences have been thoroughly investigated, the third step follows. It entails developing and integrating hardware (HW) and software (SW) on the target platform, testing and validating the system's functions, and validating its safety integrity level. Another validation is carried out at the vehicle or machine level once the object detection device is in place within the machine. This process verifies the safety function in the greater context of the overall system.

## SENSOR DETECTION CAPABILITY

One of the key points of the DIN EN 62998 standard is the demand for evidence of the sensor technology's ability to detect objects, proof that technological properties as well as systematic and environmental interference factors have been taken into account. The draft standard sets out generic requirements for this guideline, but does not specify exactly how this proof is to be furnished.



**FIGURE 1** Development process of reliable object detection factors the machine's application scenario into the design equation (© ITK Engineering)

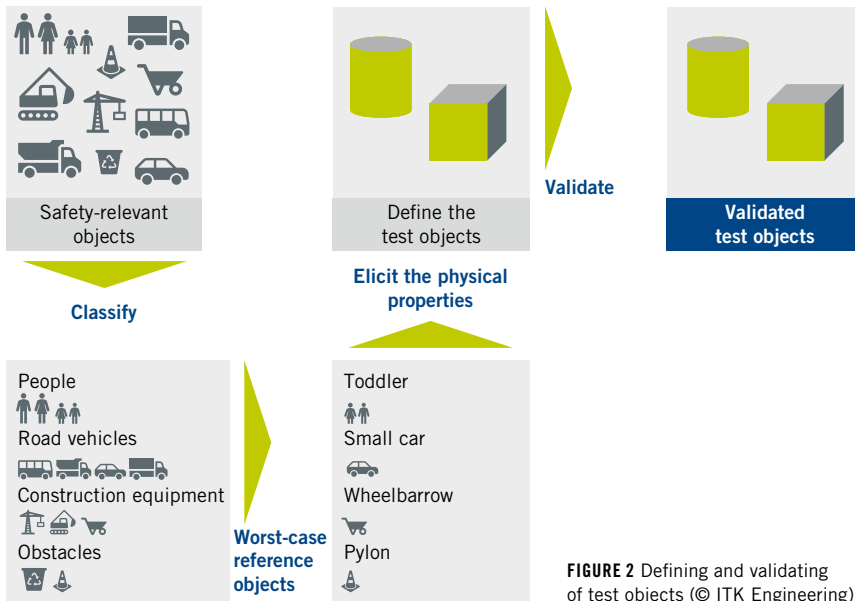


FIGURE 2 Defining and validating of test objects (© ITK Engineering)

The following section discusses in how far these specifications can be put into practice while factoring technology-specific properties into the equation.

### DEFINING AND VALIDATING TEST OBJECTS

Engineers methodically select real life test scenarios to achieve the highest possible test coverage at reasonable cost. In doing so, it is important to adapt the test scenarios to the machine's application scenario and the selected sensor technologies. However, the sensors' detection ability may have to be substantiated for many safety-relevant objects. A workable approach is to define specific test objects for the various sensor and use cases. These test objects can then serve to gather evidence. The following procedure is recommended, **FIGURE 2**:

1. classifying objects with similar characteristics (for example people, vehicles, obstacles, or static objects)
2. selection of a reference object for each object class to represent the worst case detection scenario
3. determining the typical physical properties, such as the material, shape, reflective properties, and surface finish. These are characteristics of relevance to the given sensor type's ability to detect objects
4. definition of a test object for the respective object classes based on the results from step 3

5. validation of the test objects by using the respective reference object.

Here, the sensor technology or technologies in use and the sensor's properties play a key role. These test objects have to reflect not only the real objects' geometric properties; they must also render properties of relevance to the given sensor technology. The following caveat applies to LiDAR sensors (wavelength  $\lambda = 900 \text{ nm}$ ): They have to detect diffuse reflective objects with just 1.8 % reflectance in the relevant wavelength [1]. For radar sensors, the material's dielectric properties and structural dimensions should be taken into account. Interference that prevents reliable object detection may occur if the structural dimensions are within the radiation's wave-

length range. A test object can then be constructed based on the relevant and sensor-specific properties for the respective object classes. The next step, validation, goes to ensure that the recognition probability for the test object is no higher than the one for the worst case reference object.

Validated test objects serve to systematically investigate the ability to detect objects, **FIGURE 3**. These analyses enable developers to identify recognition gaps or losses, and to take measures to prevent or detect these issues. They have to examine the entire processing chain to include logic filters aimed at preventing misidentification. It is imperative that they do not erroneously filter out objects that exist in the real world. This has to be a methodical investigation that analyzes the given sensor technology's physical principles in penetrating depth. This includes environmental influences that could impair the system's ability to detect objects. Engineers have to set out clearly defined limits – for example, the amount of precipitation – up to which the sensors' ability to detect objects can be guaranteed. The development process also has to focus on the availability of object recognition. A false positive may be acceptable in terms of functional safety, but it is certainly unacceptable for the use case.

### DEVELOPING THE SYSTEM AND INTEGRATING IT INTO THE VEHICLE

Once these investigations are wrapped

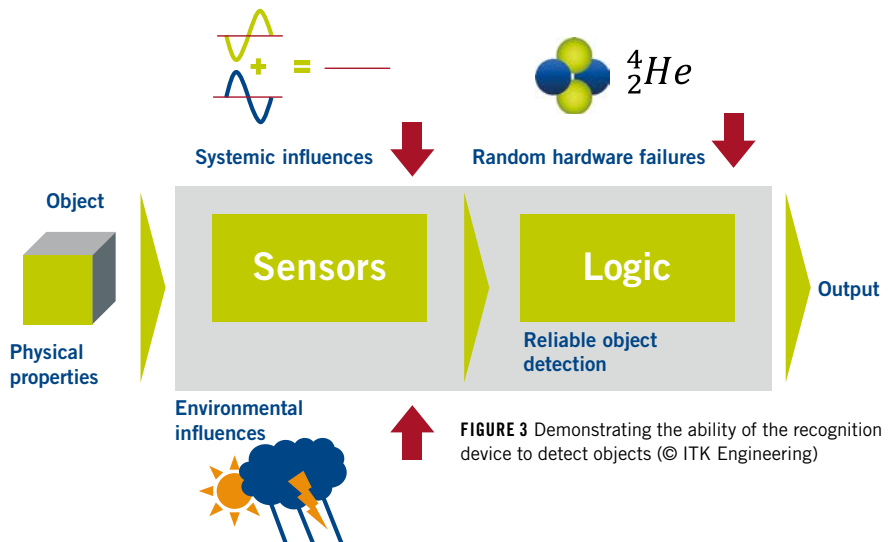


FIGURE 3 Demonstrating the ability of the recognition device to detect objects (© ITK Engineering)

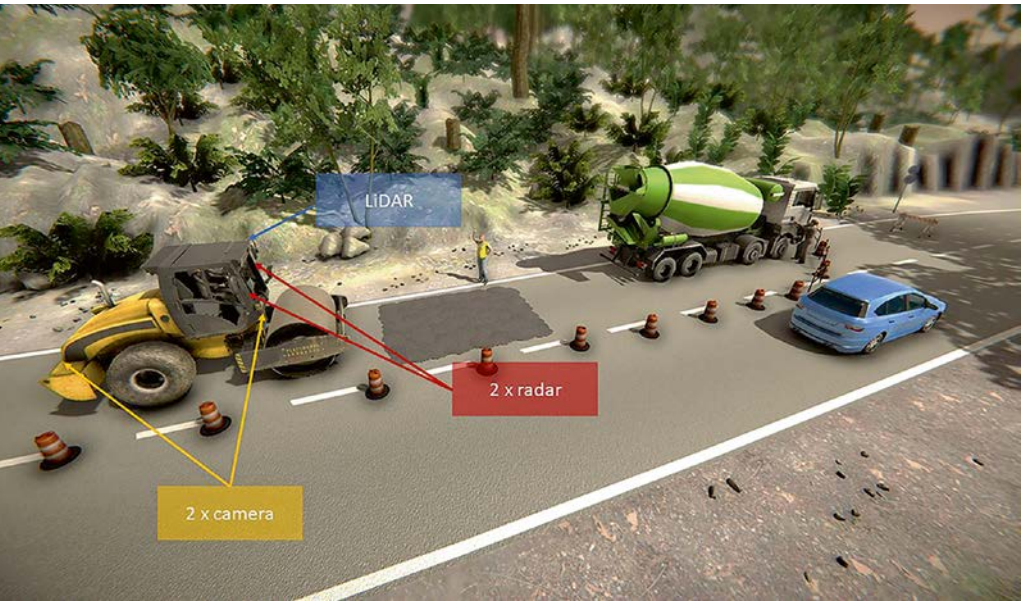


FIGURE 4 Environmental simulation featuring vehicles, sensor systems, and sensor placement (© ITK Engineering | Unity Asset Store)

up and the proposed system’s ability to reliably detect safety-relevant objects is confirmed, the system may be developed and validated in compliance with the applied standards. Engineers then integrate the object recognition device into the vehicle and conduct tests at the vehicle level to validate its overall function. They have to make sure that the system is operated within the boundaries of its detection capability and robustness in the face of environ-

mental influences as specified for its intended use.

**SENSOR SIMULATION TO SUPPORT THE DEVELOPMENT PROCESS**

The DIN EN 62998 standard also recommends simulations in addition to conventional development methods. In fact, it requires them for higher safety classes. A simulation to investi-

gate complex (multi-)sensor systems has to satisfy discriminating demands. This can only be achieved with special sensor simulation methods. To this end, a vehicle with virtual sensors is simulated in a virtual three dimensional environment, FIGURE 4. Much like real sensors, these virtual sensors generate data streams for objects in their field of vision, which are then analyzed. Vehicles, people, and objects can move around in the virtual environment and interact with the device under test. Imaging sensors, such as (stereo) cameras, generate a video stream from the sensor’s local perspective, FIGURE 5. Ray tracing is used for wave-based sensors such as LiDAR, radar, and ultrasound, FIGURE 6. This is a method whereby the emitted signal is abstracted via geometrical beams and their propagation is calculated in the 3-D environment up until the point where their reflections bounce back to the sensor. Physical models for scattering, refraction, attenuation, absorption, and the like interpret these detected beams in relation to virtual sensor data such as intensity, propagation time, etc. If this data is to be informative, the simulation will have to be realistic with images rendered in high definition. Commercial 3-D object libraries provide many different objects for designing scenes. They come with tools that enable the designer to parameterize the properties of materials and surfaces. Designers can even map out

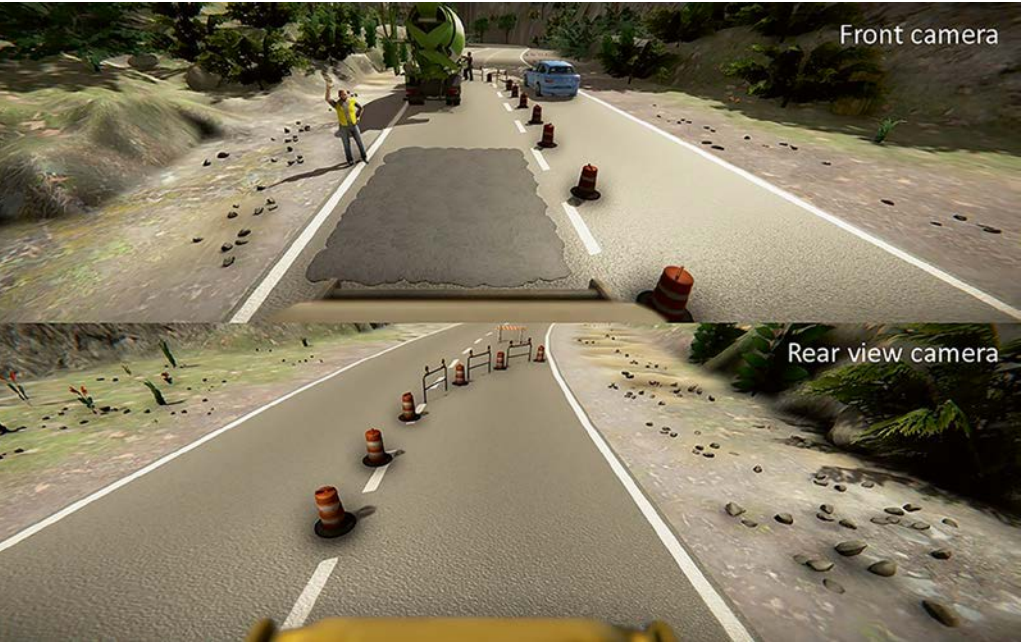
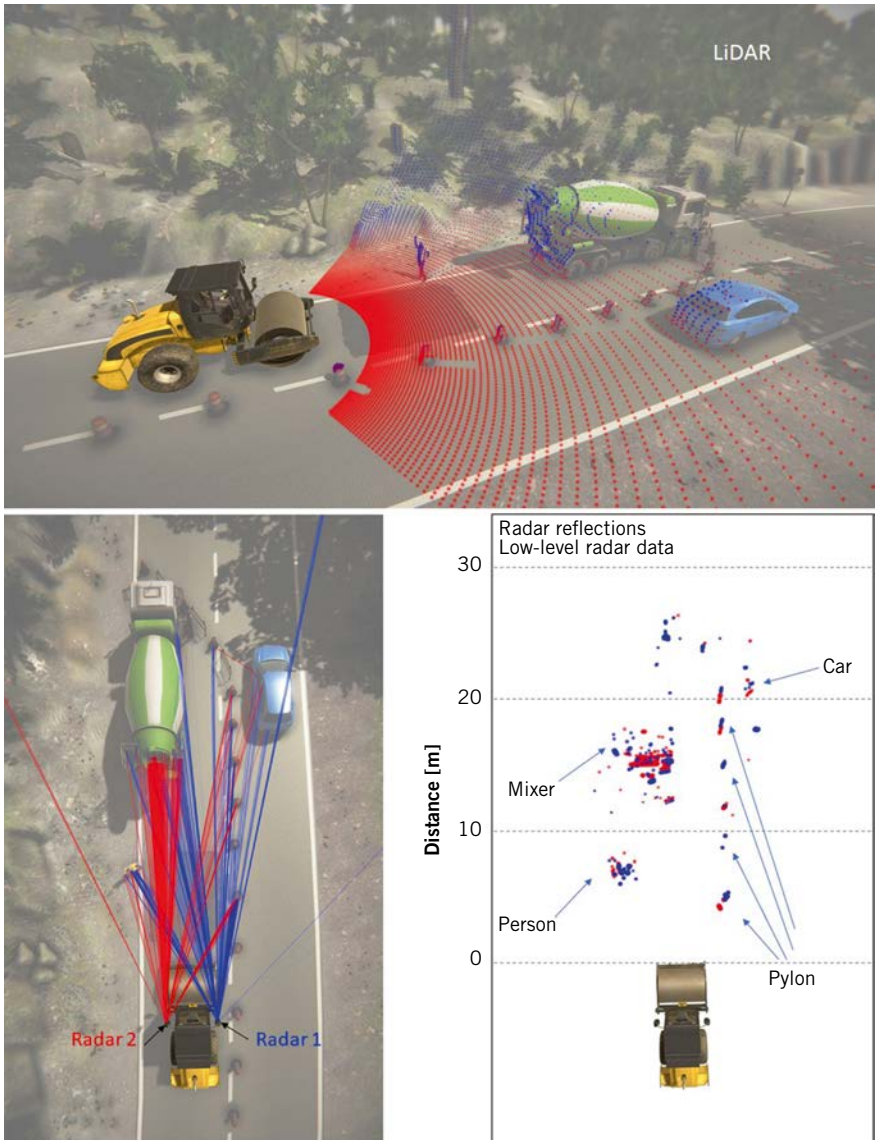


FIGURE 5 Camera simulation (© ITK Engineering | Unity Asset Store)





**FIGURE 6** LiDAR simulation (top), radar simulation (bottom left) and visualization of radar beams reflected back to the sensor (bottom right) – reflections from Radar 2 shown in red; reflections from Radar 1 shown in blue (© ITK Engineering | Unity Asset Store)

complex environments, such as industry shop floors and construction sites, with these efficient tools. Some functions are available to invoke environmental influences, for instance weather, lighting conditions, glare or reflection

that interfere with sensors and provoke false identifications or ghost targets. Others serve to analyze the effects of these influences.

Simulation is very much part of the development process. When engineers

set out to define the architecture, they have to verify the fundamental suitability of the sensor technologies to purpose. The same goes for the fields of view at potential locations on the vehicle. They then compare these findings with the specifications. As part of this validation, they conduct virtual tests to substantiate the system's ability to detect safety-relevant objects and, of course, people. This also includes Software-in-the-Loop (SiL) or Hardware-in-the-Loop (HiL) tests if software sources are at hand. Entire workflows may be tested in virtual vehicle trials once software versions of all system components are available. These results save time and spare engineers effort when validating the real life prototype. They also enable virtual pretesting to fast-track test schedules.

**SUMMARY**

Automating mobile machines is a tall order for manufacturers to fill, particularly when it comes to ensuring safety and protecting people outdoors. Rugged terrain and environmental influences preclude the use of indoor solutions. Reliable person and object detection has to be provided outdoors even when such external influences are at work. The described development process sets out in specific terms how to meet the generic requirements of DIN EN 62998 and put these specifications into practice. It also explains in how far virtualization and sensor simulation can help fast-track the development of object detection devices for outdoor applications that are indeed standard compliant, application specific, and reliable.

**REFERENCE**

[1] N. N.: Safety of machinery – Electro-sensitive protective equipment – Part 3: Particular requirements for active opto-electronic protective devices responsive to diffuse reflection (AOPDDR). DIN IEC 61496-3:2017



# ITK Engineering

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