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Road vehicles — Sensors for automated driving under adverse weather conditions — Assessment of the cleaning system efficiency

Véhicules routiers — Capteurs pour la conduite automatisée dans des conditions météorologiques défavorables — Évaluation de l'efficacité du système de nettoyage

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Foreword

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This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 35, *Lighting and visibility*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Vehicles with automated driving systems (ADS) need more sensors, such as radars, lidars and cameras. These components are located outside the vehicle, which means they are exposed to weather conditions that can cause contamination on sensitive surfaces. This can affect visibility, which can impair safe driving.

For Level 1 and Level 2 ADS (defined in ISO/SAE PAS 22736), any failure in sensor detection is overcome by the driver immediately recovering control of the vehicle. From Level 3 onwards, the driver alone cannot guarantee vehicle safety, and a scenario-based safety evaluation must be performed (see ISO 34502).

Sensor technology is evolving rapidly and becoming more robust. It is therefore difficult to determine single set of uniform criteria on how clean sensors have to be for automated driving systems to perform as expected. This can also depend on the role of the given sensor.

Regardless of which sensor is used to determine a vehicle's environment, the front surface of a sensor is kept clean by a system that maintains visibility performance. Evaluating the cleanliness of the front surface of a sensor after a cleaning operation determines the efficiency of the cleaning systems.

Road vehicles — Sensors for automated driving under adverse weather conditions — Assessment of the cleaning system efficiency

1 Scope

This document proposes a standard test procedure to assess the efficiency of cleaning systems for sensors. It addresses the following conditions:

— dust/mud

— frost/snow

— mist/rain

This document does not propose a preferred cleaning system. This document is intended to be technologically neutral and performance-oriented. Its focus is on the cleaning system, not on sensor detection. The assessment method specified in this document is therefore fully independent from sensor technology and from the data generated by the sensor when in use.

This document is entirely focussed on the cleanliness of the front surface of the sensor.

This document does not address continuous contamination, such as continuous rain. This is because in these circumstances, the efficiency of the cleaning system can only be assessed from inside the sensor.

For non-continuous contamination, this document includes intermittent cleaning, which is considered a succession of cleaning cycles that are launched periodically, as defined in 3.2.

The test does not include specific day time/night time conditions. This is because these conditions have no impact on the results and the average clean remains similar. However, more efficient cleaning can be done at night.

This document does not cover contamination with insects due to the challenges of ensuring homogeneous application.

This document does not provide indicators for sensor performance. This document is limited to the evaluation of the removal of contamination from surfaces.

This document does not include evaluation on preventive measures taken in the installation design. The aerodynamic design affects how mud sprayed from a moving vehicle or rain droplets can reach and build-up on the sensor's frontal protection layer. Countermeasure design is beyond the scope of this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 19403-2, *Paints and varnishes — Determination of the surface free energy of solid surfaces by measuring the contact angle*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
cleaning system
system able to remove contamination from the sensor surface by using an extrinsic washing procedure, by intrinsically adopting contaminant repelling treatment, or a combination of both

Note 1 to entry: Intrinsic cleaning refers to treatment that reduces the ability of contaminants to adhere to the surface of the sensor.

3.2
cleaning cycle
set of successive operations of the *cleaning system* (3.1), launched by an impulsion initiated either manually or automatically

3.3
relative wind
wind resulting from the ego motion of the vehicle in motion in a windless environment

Note 1 to entry: For practical reasons, the test may be performed within a wind tunnel with the equipment kept steady.

4 Principle of the cleaning efficiency assessment

The test described in this document evaluates how efficiently the system removes contamination from the frontal surface of the outermost window of the sensor. This is done by comparing contaminants observed visually using photographic images (see Figure 1).

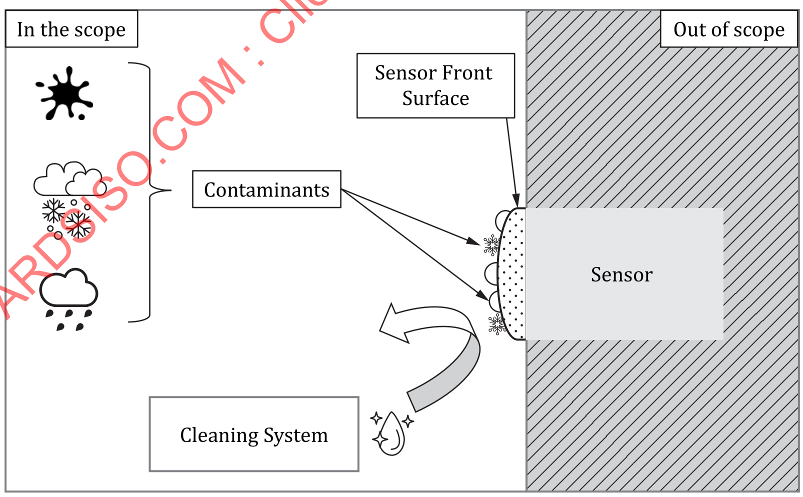


Figure 1 — Cleaning efficiency assessment principle

The surface is evaluated in three stages:

a) the initial clean stage;

b) the contaminated stage;

c) the clean stage after the cleaning cycle.

Figure 2 illustrates a simplified stage of the physical test and the use of photographic images that capture the following:

— the sensor surface before the application of the contaminant (picture 1),

— after the application of the contaminant and the defined cure process when applicable (dry/wet) (picture 2),

— after the cleaning cycle (picture 3).

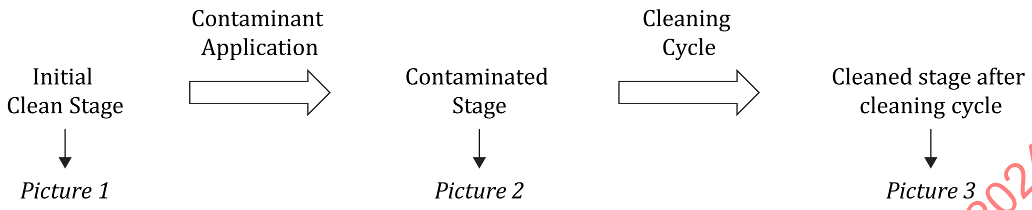


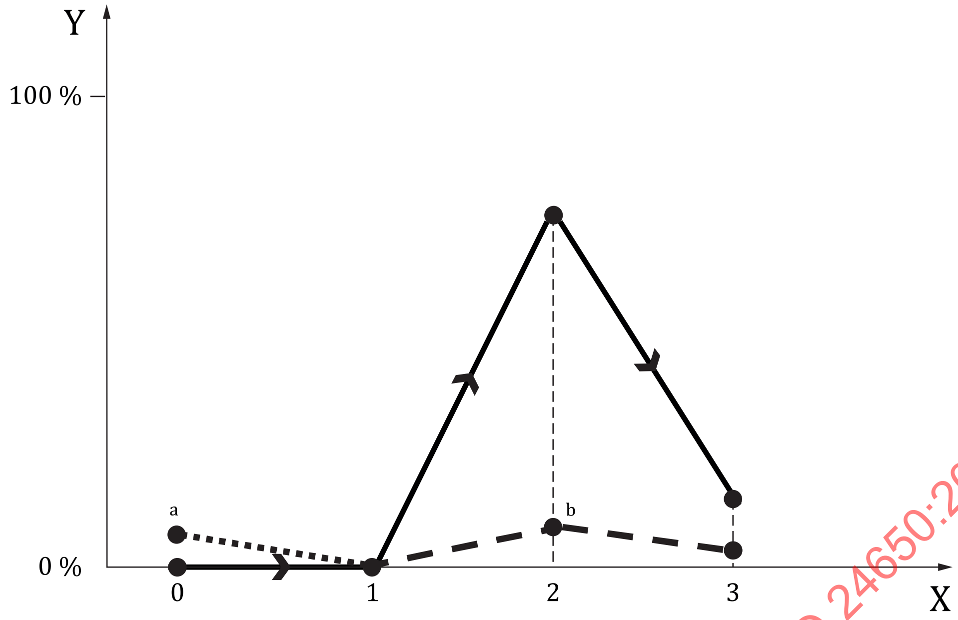
Figure 2 — Test principle

Quantitative evaluation is performed by analysing the contamination left on the front surface of a sensor, e.g. its opening window area, which is of interest given its size. The contaminant is captured by photographic means. The image is then assessed to gauge the proportion of the contaminant.

This document does not take into account the volume of contaminants removed. Instead, it considers the physical area of the front surface of the sensor from which contamination has been removed (see 6.4). The test procedure determines the contaminated area by taking advantage of how small particles laid on a flat surface diffuse light. Residual contaminant particles on the front surface of the sensor diffuse the incoming reference light. Removing these contaminants will result in less diffusion of this light. This leaves a visible difference where contamination was successfully removed by the cleaning operation.

Quantitative cleaning efficiency is based on comparing the areas of the cleaned and contaminated surfaces between pictures 1, 2 and 3 (see Figure 3).

The relative efficiency of the cleaning system is determined by the size of the clean surface after cleaning. The surface area of the applied contamination is compared with the contaminated surface after cleaning.



Key

X event number

Y contamination coverage [%] (remaining residue in respect to the region of interest)

0 pre-defined initial stage

1 after pre-cleaning (picture 1)

2 after contamination (picture 2)

3 after cleaning cycle (picture 3)

[a] As defined in 5.5.1, the status of the surface can correspond to case 2 or case 3.

[b] For the intrinsic sensor cleaning system, contaminant accumulation can be either partial or fully prevented.

Figure 3 — Cleaning efficiency measurement

The test is performed in two steps:

In step one, the contaminant is applied. How efficiently the contaminant is applied depends on whether the front surface of the sensor has means of preventing the adhesion of contaminants.

EXAMPLE A hydrophobic coating that repels water droplets.

In step two, the active cleaning operation takes place. Treatment is applied to the front surface of the sensor to remove contamination.

For sensor systems that do not have incorporated cleaning systems, the assessment is performed by evaluating how efficiently contamination is prevented. This is done by determining how much of the front surface of the senor is affected and covered by contaminants.

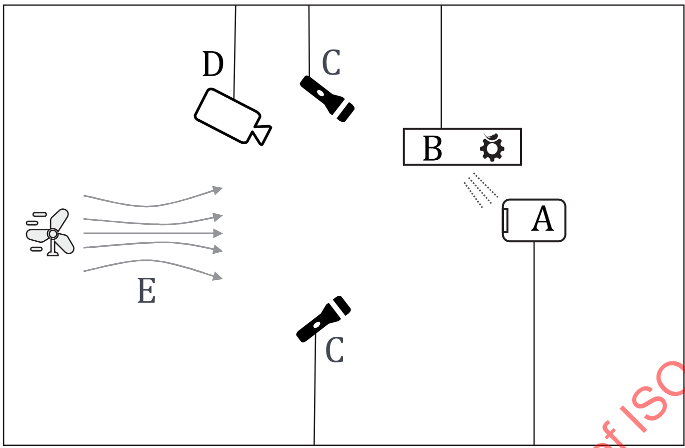
The absolute efficiency of the cleaning system is determined by the size of the clean surface after a cleaning cycle compared to the clean surface at the initial state.

For an intrinsic cleaning characteristic, where the front surface of the sensor is treated to make it harder for contaminants to adhere, its performance over time shall be evaluated separately. This additional evaluation is required because the intrinsic cleaning properties, i.e. the contaminant repellent properties, are often achieved by adding or modifying the chemical properties of the surface. These are prone to deteriorate over time.

5 General testing conditions

5.1 Installation

The cleaning system and the sensor surface shall be installed either in their original position in the vehicle or on a test bench provided that their position, orientation and behaviour remain representative of the vehicle conditions throughout the test (Figure 4).



Key

A device under test (sensor)

B cleaning system

C light source

D camera

E air flow (wind)

Figure 4 — Installation on a test bench

5.2 No-load cleaning cycle

Prior to launching a test session, the key characteristics of the cleaning system shall be verified with a no-load cleaning cycle. The cleaning system shall be adjusted if necessary. The precise list of characteristics to be verified depends on the cleaning system technology and therefore cannot be provided in this document.

5.3 Surface contamination

For practical reasons, the contaminant may be applied to the sensor surface off the test bench, provided that the position of the sensor is the same between pictures 1, 2 and 3 (see Figure 2).

5.4 Environmental conditions

The controlled environmental conditions are the temperature, relative humidity and aerodynamic conditions. The test under dynamic conditions aims to better represent real conditions of use, in particular natural wind and vehicle speeds.

Four sets of standard environmental test conditions (A, B, C, D) are considered (see Table 1).

Table 1 — Set of standard environmental test conditions

Environmental test conditions	A	B	C	D
Temperature	23 ± 2 °C	23 ± 2 °C	−8 ± 2 °C	−18 ± 3 °C
Relative humidity	50 ± 5 %	50 ± 10 %	N/A	N/A
Aerodynamic	Static	Dynamic	Static	Static

For aerodynamic conditions (tested preferably using a wind tunnel), the following relative wind should be used:

— static: no relative wind;

— dynamic: relative wind (30, 50, 70, 90, 110, 130) km/h.

The applicability of the environmental conditions described in Table 1, for both the contamination phase and for the cleaning cycle, are provided in Table 2 according to the type of contaminant.

Table 2 — Applicability of environmental conditions (Table 1) vs contaminant types

Contaminant types	Environmental conditions during surface contamination			Environmental conditions during cleaning cycle	
	A	B	C or D	A or B	C or D
Dust/mud	Possible	N/A	N/A	Possible	Possible
Frost/ice	N/A	N/A	Possible	N/A	Possible
Mist/rain	Possible	N/A	N/A	Possible	N/A

EXAMPLE For dust/mud testing, contamination is achieved under condition A only and the cleaning cycle is performed under any of the four conditions A, B, C or D.

5.5 Sensor surface state preparation

5.5.1 Pre-cleaning

The surface is subject to different types of contamination or aging degradation which may affect cleaning performance. To obtain repeatable and reliable results, the frontal surface of the device under test (DUT) shall be exposed to pre-test conditions before it is exposed to the test conditions. These pre-test conditions shall depend on the aim of the evaluation. They shall fall under one of the following cases:

— case 1: initial post-factory, pristine stage with no contamination and zero aging;

— case 2: aged surface with pre-determined wear-out consideration;

— case 3: regenerated surface after test.

The surface is cleaned before the test to remove stain residue or other residual material that may affect the results of the evaluation. Unless the DUT is contaminated with oily substances, it is enough to rinse the frontal surface of the sensor with distilled water and dry it with a clean, lint-free cloth in a way that does not modify the surface tension. Care shall be taken to not use cloth that contains softener as this can contaminate the surface.

5.5.2 Surface tension

Prior to launching a test session, the contact angle of the sensor surface shall be measured according to ISO 19403-2 with di-ionized water as the test liquid. Users may make specific preparations for the surface state in order to simulate the state of the surface when new/aged depending on the target evaluation.

5.6 Lighting conditions

The following lighting conditions shall be met on the surface of the sensor:

— light intensity: (500-1 000) lx;

— light temperature: (6 500 ± 500) K (daylight);

— no reflection from camera lens or lighting system.

NOTE The lighting adopted in this test procedure is for visually inspecting the contaminant using an evaluation camera.

5.7 Camera and shooting conditions

The camera shall:

— be able to deliver a minimum of eight-bit gradation in a monochrome image (either a monochrome or colour camera can be used as long as there is no loss of gradation);

— have a shutter speed that can be set to faster than 1/20 (sec^{-1}) under the lighting conditions outlined in 5.6;

— produce images where the presence of contamination can be determined at a resolution of 150 um per pixel or higher;

EXAMPLE A 5 megapixel with 2 464 x 2 056-pixel camera can deliver images resolving 50 um if the area is smaller than 123 mm x 102,8 mm

— produce images in a non-compressed format (e.g. TIFF).

NOTE 1 The recommended focal length of the camera is between 35 mm and 50 mm in "35 mm film equivalent focal length".

NOTE 2 For sensor systems that have protective covers made of clear material, a material that absorbs black light is placed on the back of the protective cover to clearly differentiate the contaminated area from the uncontaminated area where its background will be captured in an image.

5.8 Specific situations

5.8.1 Sensor surface

When the sensor is located behind a surface of the vehicle, a material that is representative of this surface shall be tested in place of the sensor surface.

5.8.2 Cleaning system

When the cleaning system needs a washing fluid, the tested fluids should be one of those listed in Annex A.

5.9 Test session

To get an appropriate accuracy of results, the test should be performed three times in a given test session.

Between each test, the sensor shall be cleaned according to 5.5.1.

6 Dust/mud testing

6.1 Test mixture preparation

Mud is prepared by dispersing dust in water. A non-exhaustive list of example dust compositions is provided in Annex B, which also outlines standards for dispersion procedures.

Precautions shall be taken so that the mud does not dry or decant until it is applied to the sensor surface.

6.2 Test equipment

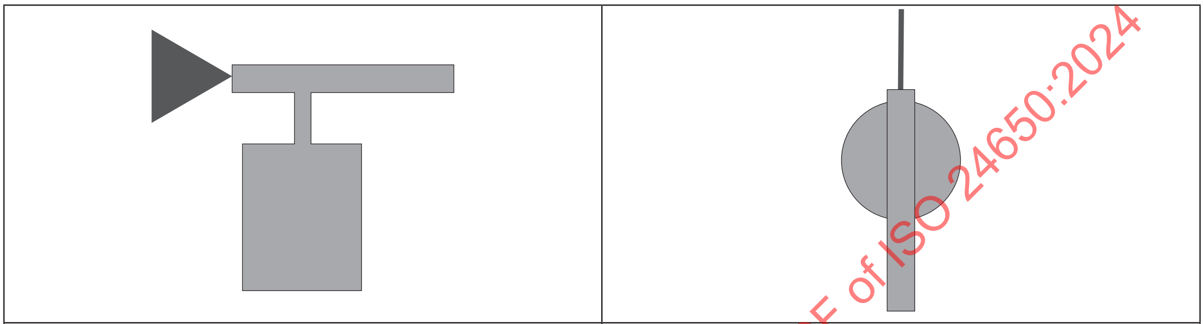
The following test equipment is recommended:

— a paint gun with the following parameters:

  — 1 l capacity, 1,5 mm tip, 6,35 mm air inlet, 6 bar[1)] maximum air pressure

  — pressure: 3 ± 0,25 bar[1] when the gun is activated

  — the spray orientation outlined in Figure 5



a) Side view | b) Top view

Figure 5 — Orientation of the spray of the paint gun

— a heat gun that can heat up to 60 °C;

— an air regulator valve.

6.3 Preparation of the equipment

The gun nozzle shall not be clogged

The gun shall be primed with the fluid before spraying on any sensor.

6.4 Test procedure

a) Use the test mixture outlined in 6.1.

b) Take picture 1.

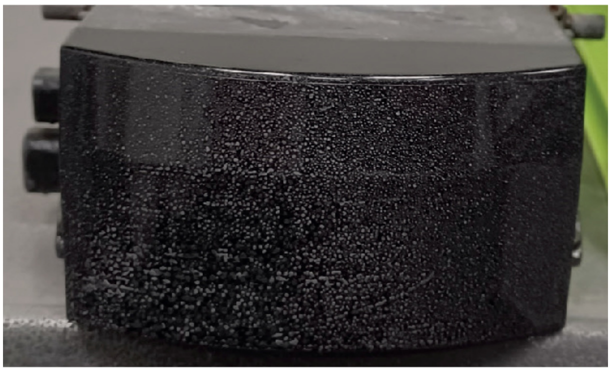
c) When the environmental conditions are met, apply one layer of the test mixture using the paint gun, positioned in front of the sensor at a distance of 50 cm and perpendicular to the surface. Spraying should start from the outside of the sensor on the left side and cover the sensor from left to right at an average speed of 0,3 m/s.

d) Verify visually that the mud is applied uniformly on the sensor surface and that the entire field of view is covered (see Figure 6).

1) 1 bar = 0,1 MPa = 10^5 Pa; 1 MPa = 1 N/mm2.

a) Uniform contamination

Correct application



b) Not fully dried

c) Not homogeneous

d) Lack of material

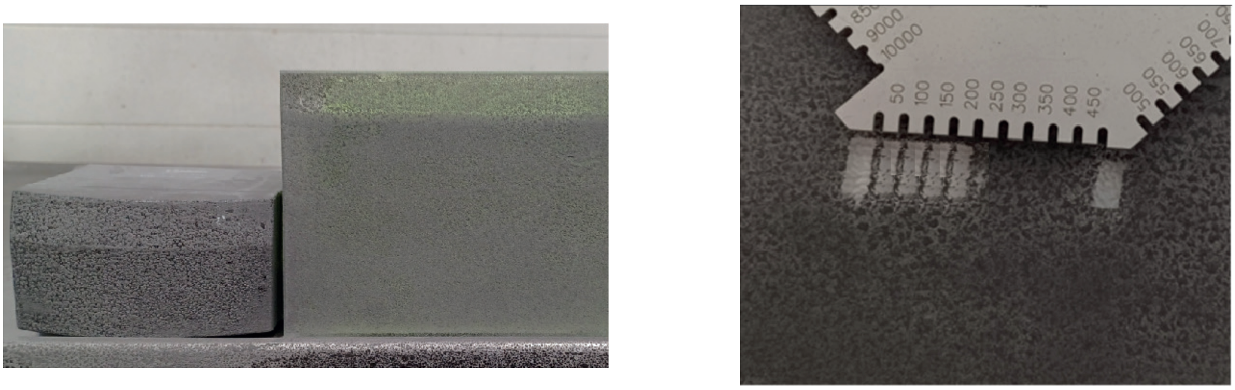
e) Not homogeneous

Incorrect application

Figure 6 — Examples of correct and incorrect applications

e) Dry the mud using a heat gun by setting the temperature to 60 °C or the lowest temperature available, positioned no closer than 50 cm from the sensor surface. The layer of mud is considered to be applied when totally dry.

f) Check the quality, area density and thickness of the mud. Another flat component (or reference sample) installed near the sensor may be used as a control (see Figure 7).



a) Left: sensor sample; right: reference sample **b) Film thickness gauge**

Figure 7 — Example of reference sample for mud quality and thickness control

g) Apply a new layer (repeat steps c) to f)) until the total quantity of dried mud corresponds to 12 g/m^2 ± 0,5 g/m^2 or (200-250) µm thickness. The recommended means of control for weight density and thickness are shown in Figure 7.

h) Take picture 2.

i) Launch the cleaning cycle (see Figure 8).

Figure 8 — Example of sensor surface after cleaning cycle

j) When the cleaning cycle is finished, dry the sensor surface under same conditions as e) (see Figure 9).

Figure 9 — Example of sensor surface after drying (with remaining contaminant)

k) Take picture 3.

l) If a new test is needed, clean the sensor surface according to 5.5.1 and then repeat steps a) to k).

NOTE 1 If the wet contaminant spray is applied uniformly to both the DUT and the reference sample, the thickness of the contamination can be considered the same on both surfaces .

NOTE 2 The film thickness gauge corresponds to the comb gauge described in ISO 2808. The gauge is placed at a right angle on the reference sample and then scratched with enough pressure to ensure that the reference teeth are in contact with the substrate. The contaminant thickness is slightly thinner than the smallest tooth not in contact with the substrate (i.e. not scratched). See Figure 7, b) which shows contamination over 200 μm but less 250 μm.

7 Frost/ice testing

7.1 Frost/ice preparation

Frost or ice are generated in situ by pulverizing water on the sensor surface. This is done under the environmental test conditions C for frost and D for ice (see Tables 1 and 2).

The appropriate volume of water is stored in a separate climate chamber at (3 ± 2) °C to create frost and (20 ± 2) °C to create ice.

7.2 Test equipment

The test equipment is as follows:

— a spray gun with a nozzle of 1,7 mm in diameter and a liquid flow rate of 0,395 l/min, and which can produce a fan pattern of 300 mm in diameter on the glazed surface at 200 mm from that surface;

— an air regulator valve.

7.3 Preparation of the equipment

If the test is performed on a vehicle, let the vehicle cool down overnight under conditions C or D. If the test is performed on a fixture, wait at least 3 h so that the temperature specified for C or D is stabilized.

In addition, the instructions outlined in 6.3 shall be respected.

7.4 Test procedure

a) Take picture 1.

b) When the environmental conditions are met (i.e. the temperature that water droplets freeze on meeting the surface of the sensor on the DUT), put the nozzle in place so that the sensor surface is completely covered.

c) Spray the water on the sensor surface by fully pressing the trigger for less than 2 s. Spray several times if necessary to reach the target contamination.

d) Wait until the frost/ice is stabilized, (10-15) min.

e) When applying the water spray, ensure that the frost/ice has uniform density and thickness over the evaluation area. Another flat reference component can be installed near the sensor in order to verify the thickness of the contamination.

   Minimum thickness requirement: 350 μm for frost and ice. Recommended means of control: film thickness gauge.

f) Take picture 2.

g) Launch the cleaning cycle.

h) When the cleaning cycle is finished, wait 1 min so that potential residues of frost/ice stabilize.

i) Take picture 3.

j) If a new test is needed, clean the sensor surface according to 5.5.1 and then repeat steps a) to i).

8 Mist/rain testing

8.1 Water specification

Water hardness: not exceeding 200 ppm

Temperature: 23 °C ± 5 °C

Additives can be added to the water to adjust water opacity and make droplets easier to detect, as long as these additives do not modify the behaviour of the water during the test, in particular the efficiency of the cleaning process.

8.2 Test equipment

For mist, the test equipment is a spraying system capable of providing water droplets in appropriate sizes (see Table 3).

Table 3 — Droplet sizes for mist spraying

	Dry fog	Fine fog	Fine drizzle
Droplet size	< 10 µm	~ 50 µm	200 µm

For rain, the test equipment is a spraying system capable of providing water droplets with appropriate precipitation rates (see Table 4).

Table 4 — Precipitation rates for rain spraying

	Light rain	Moderate rain	Heavy rain	Very heavy rain	Extreme rain
Precipitation rates (mm/h)	1,0	4,0	16	50	➢ 50
Typical diameters (for information only)	0,5 mm	2,0 mm	5,0 mm		

Characteristics of the spraying system shall be respected according to the supplier prescriptions in order to get appropriate diameters or precipitation rates.

NOTE Characteristics that can influence the diameters or precipitation rates: tube length, nozzle diameter, nozzle type, aspersion distance, opening cone.

8.3 Preparation of the equipment

The following points shall be respected:

— make sure that the spraying system is not clogged;

— apply the settings provided by the supplier prescriptions to the spraying system:

  — water flow/pressure

  — air flow/pressure

— prime the spray gun before spraying on any sensor.

8.4 Test procedure

a) Take picture 1.

b) When the environmental conditions are met, place the nozzle to ensure that the sensor surface is completely covered.

c) Activate the spraying system to get a stable and continuous spray.

d) Stop the spraying system after 1 min.

e) Take picture 2.

f) Launch the cleaning system cycle.

g) At the end of the cleaning cycle, take picture 3.

h) If a new test is needed, clean the sensor surface according to 5.5.1 and then repeat steps a) to g).

9 Assessment of the efficiency of the cleaning system

9.1 Picture analysis

The following steps shall be executed to pictures 1, 2 and 3 (see Annex C for examples):

a) Recover pictures 1, 2 and 3 captured as described during the relevant test procedure.

b) If necessary, convert the original RGB image to greyscale.

c) The image shall be cropped to remove areas beyond the sensor surface.

   Select the area of interest corresponding to the function-relevant sensor surface. The area to be cropped shall have the same size and number of pixels in pictures 1, 2 and 3. A suitable image editing software shall be used.

d) Create a greyscale histogram of the selected area. This histogram is used to define the first estimated value of the threshold for binarization.

e) Convert the monochrome picture result of list item c), displaying all edited areas in the test, into a black-and-white (b/w) picture by using the first estimated threshold determined in d).

   Compare the monochrome picture with the b/w picture and (subjectively) evaluate the correctness of the discrimination with regards to contaminated and cleaned areas.

   Optimise the threshold in iterative, subsequent loops until the best possible agreement is achieved between the two pictures.

   An example of iterative threshold determination is provided in Annex D.

EXAMPLE Considering the grey scale, which has values from 0 to 255 (8-bit), and that the threshold is set to a grey value of 17, all pixels with a grey value from 0 to 17 are identified as cleaned (black), and all pixels with a grey value from 18 to 255 are identified as contaminated (white).

9.2 Cleaning system efficiency calculation

Resistance to contamination is calculated using the following formula:

$$R_C = \frac{n_{b,P(2e)}}{n_{b,P(1e)}} \cdot 100$$

where

R_C	is the resistance to contamination, expressed in %;
$n_{b,P(2e)}$	is the number of black pixels in picture (2e);
$n_{b,P(1e)}$	is the number of black pixels in picture (1e).

NOTE Black pixel indicates that the area is uncontaminated (see 9.1).

The relative efficiency of the cleaning system is calculated using the following formula:

$$E_R = \left(1 - \frac{n_{w,P(3e)}}{n_{w,P(2e)}}\right) \cdot 100$$

where

E_R	is the relative efficiency of the cleaning system, expressed in %;
$n_{w,P(2e)}$	is the number of white pixels in picture 2;
$n_{w,P(3e)}$	is the number of white pixels in picture 3.

NOTE White pixel indicates a contaminated area. This is because the reference light is diffused, and therefore bright, which makes the area to look white.

The absolute efficiency of the cleaning system is calculated using the following formula:

$$E_A = \frac{n_{w,P(3e)}}{n_{b,P(1e)}} \cdot 100$$

where E_A is the absolute efficiency of the cleaning system, expressed in %;

9.3 Specific areas of interest

Due to the wide variety of sensor geometries, the area selected at step 9.1 c) may be further divided into several areas in order to emphasize the zone with the highest signal transmission. When there are several areas, each area may be subject to specific requirements.

Examples of areas of interest are given in Annex E.

9.4 Expression of results

Cleaning efficiency shall be expressed as the average of the results obtained during the test session.

The test report shall contain the following information:

— sensor description (e.g. type and trade reference, ageing history);

— sensor surface characteristics:

  — specific area of interest as defined in 9.3;

  - surface state as measured in 5.5.2.
- fluid consumption per cleaning cycle, if applicable;
- energy consumption per cleaning cycle, if applicable;
- environmental conditions as defined in 5.4;
- cleaning cycle duration;
- the International Standard used (including its year of publication);
- the result(s), including a reference to the clause which explains how the results were calculated;
- any deviations from the procedure;
- any unusual features observed;
- the date of the test.

Annex A
(informative)

Selected washer fluids

Unless otherwise specified, the characteristics of selected washer fluids to be used in 5.8.2 are as follows:

— water with water hardness 205 mg/l;

— solution of water/ethanol 50 % V/V.