PD IEC/TS 61496-4-3:2015

BSI Standards Publication

Safety of machinery — Electro-sensitive protective equipment

Part 4-3: Particular requirements for equipment using vision based protective devices (VBPD) — Additional requirements when using stereo vision techniques (VBPDST)

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TECHNICAL SPECIFICATION

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Safety of machinery – Electro-sensitive protective equipment – Part 4-3: Particular requirements for equipment using vision based protective devices (VBPD) – Additional requirements when using stereo vision techniques (VBPDST)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SAFETY OF MACHINERY – ELECTRO-SENSITIVE PROTECTIVE EQUIPMENT –

Part 4-3: Particular requirements for equipment using vision based protective devices (VBPD) – Additional requirements when using stereo vision techniques (VBPDST)

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

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IEC TS 61496-4-3, which is a technical specification, has been prepared by IEC technical committee 44: Safety of machinery – Electrotechnical aspects.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
44/711/DTS	44/722/RVC

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

This part is to be used in conjunction with IEC 61496-1:2012.

This part supplements or modifies the corresponding clauses in IEC 61496-1:2012 to specify particular requirements for the design, construction and testing of electro-sensitive protective equipment (ESPE) for the safeguarding of machinery, employing vision based protective devices (VBPD) using stereo vision techniques (VBPDST) for the sensing function.

Where a particular clause or subclause of Part 1 is not mentioned in this Part 4-3, that clause or subclause applies as far as is reasonable. Where this part states "*addition*", "*modification*" or "*replacement*", the relevant text of Part 1 shall be adapted accordingly.

Clauses and subclauses which are additional to those of Part 1 are numbered sequentially, following on the last available number in Part 1.Terminological entries (in Clause 3) which are additional to those in Part 1 are numbered starting from 3.4301. Additional annexes are lettered from AA onwards.

A list of all parts in the IEC 61496 series, published under the general title *Safety of machinery – Electro-sensitive protective equipment*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

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INTRODUCTION

An electro-sensitive protective equipment (ESPE) is applied to machinery presenting a risk of personal injury. It provides protection by causing the machine to revert to a safe condition before a person can be placed in a hazardous situation.

The working group responsible for drafting this technical specification was concerned that, due to the complexity of the technology, there are many issues that are highly dependent on analysis and expertise in specific test and measurement techniques. In order to provide a high level of confidence, independent review by relevant expertise is required. They considered that if this high level of confidence could not be established these devices would not be suitable for use in safety related applications.

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SAFETY OF MACHINERY – ELECTRO-SENSITIVE PROTECTIVE EQUIPMENT –

Part 4-3: Particular requirements for equipment using vision based protective devices (VBPD) – Additional requirements when using stereo vision techniques (VBPDST)

1 Scope

Replacement:

This part of IEC 61496 specifies requirements for the design, construction and testing of electro-sensitive protective equipment (ESPE) designed specifically to detect persons or parts of persons as part of a safety-related system, employing vision-based protective devices (VBPDs) using stereo vision techniques (VBPDST) for the sensing function. Special attention is directed to features which ensure that an appropriate safety-related performance is achieved. An ESPE may include optional safety-related functions, the requirements for which are given in Annex A of IEC 61496-1:2012 and this Technical Specification.

This part of IEC 61496 does not specify the dimensions or configurations of the detection zone and its disposition in relation to hazardous parts for any particular application, nor what constitutes a hazardous state of any machine. It is restricted to the functioning of the ESPE and how it interfaces with the machine.

The detection principle is based on the evaluation of images from different viewing points (stereoscopic view) for the determination of distance information. This distance information is used to determine the location of an object(s).

– This part of IEC 61496 is limited to vision based ESPEs with distances (stereo base) and directions between the different imaging devices fixed during manufacture.
– It is limited to vision based ESPEs, with a minimum distance from the sensing device to the detection zone of 4 times of the stereo base.
– It is limited to vision based ESPEs that can detect objects with at least 5 pixel diameter in the image plane.
– It is limited to vision based ESPEs that do not require human intervention for detection.
– It is limited to vision based ESPEs that detect objects entering into or being present in a detection zone(s).
– It is limited to VBPDSTs employing radiation at wavelengths within the range 400 nm to 1 500 nm.
– This part of IEC 61496 does not address those aspects required for complex classification or differentiation of the object detected.
– This part of IEC 61496 does not consider the aspects of a moving ESPE installation.

Additional requirements and tests can apply in the following cases:

– Use of multi-spectral (colour) techniques;
– Setups other than as shown in Figures of 4.1.2 (e.g. changing backgrounds, horizontal orientation of the optical axis with respect to the floor);
– Intended for outdoor applications.

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This technical specification is relevant for VBPDSTs having a stated detection capability up to 200 mm.

This technical specification may be relevant to applications other than those for the protection of persons or parts of persons like arm or fingers (in the range 14 mm to 200 mm), for example the protection of machinery or products from mechanical damage. In those applications, additional requirements can be necessary, for example when the materials that are to be recognized by the sensing function have different properties from those of persons.

This technical specification does not deal with EMC emission requirements.

2 Normative references

Addition:

IEC 60825-1:2014, *Safety of laser products – Part 1 – Equipment classification and requirements*

IEC 61496-1:2012, *Safety of machinery – Electro-sensitive protective equipment – Part 1: General requirements and tests*

IEC 62471, *Photobiological safety of lamps and lamp systems*

ISO 13855:2010, *Safety of machinery – Positioning of safeguards with respect to the approach speeds of parts of the human body*

ISO 20471, *High visibility clothing – Test methods and requirements*

3 Terms and definitions

Replacement:

3.3
detection capability
ability to detect the specified test pieces (see 4.2.13) in the specified detection zone

Note 1 to entry: Detection capability is measured by the size of an object that can be detected. An increase in detection capability means that a smaller object can be detected.

[SOURCE: IEC 61496-1:2012, 3.3, modified – text changed to make more relevant to vision based sensors.]

3.4
detection zone, <of a VBPDST>
three-dimensional volume (for example, in the shape of a pyramid or cone) within which a specified test piece will be detected by the VBPDST

3.5
electro-sensitive protective equipment
ESPE

Addition:

Note 3 to entry: Illumination unit(s), if applicable, is/are part(s) of the sensing device.

Additional definitions:

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3.4301
minimum detection zone
lowest dimension of the detection zone for a test piece moving with maximum speed

Note 1 to entry: This is the lowest dimension that ensures the integrity of the detection capability.

3.4302
evaluation images, pl
set of images which are used by the detection algorithms

SEE: Figure 1.

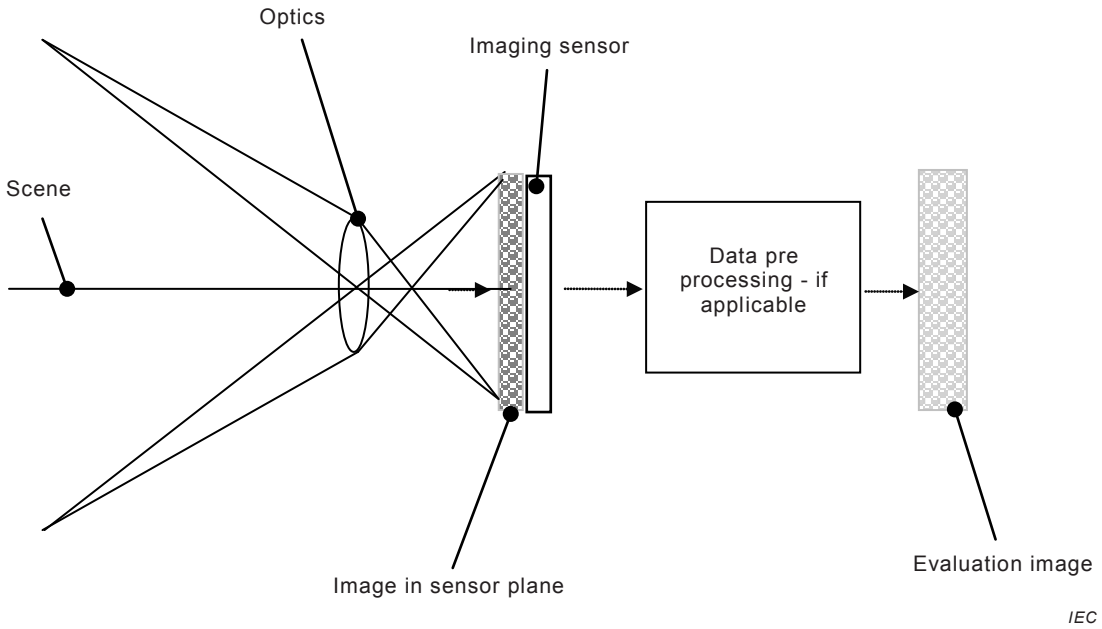

Figure 1 – Image planes in imaging device of a VBPDST

3.4303
image, <of a VBPDST>
snapshot representation of the scene in different planes of the VBPDST in form of a two dimensional pixel matrix

3.4304
vision based protective device using stereo vision techniques
VBPDST
VBPD with two or more imaging devices using stereo vision techniques

3.4305
imaging sensor
opto-electronic device which produces electrical signals representing the characteristics of an image

SEE: Figure 1.

3.4306
imaging device
combination of an imaging sensor, optics and the processing unit (if applicable)

SEE: Figure 1.

Note 1 to entry: The imaging devices are part of the sensing device.

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3.4307
operating distance
distance measured along the z-axis of the sensing device coordinate system

3.4308
pixel, <of a sensor>
smallest light sensitive element of an imaging sensor

3.4309
pixel, <of an image>
area of the smallest element that can be distinguished from its neighbouring elements

3.4310
ambient illumination technique
AIT
technique that relies on scene lighting for illumination and contrast to obtain range measurements

3.4311
pattern projection technique
PAPT
technique that uses a special projection to enhance the contrast of a scene

3.4312
sensing device coordinate system
coordinate system oriented to the sensing device

Note 1 to entry: Typically the z-axis is parallel to the optical axis of one imaging device.

3.4313
tolerance zone
zone outside of and adjacent to the detection zone within which the specified test piece is detected with a probability of detection lower than the required probability within the detection zone

Note 1 to entry: The tolerance zone is necessary to achieve the required probability of detection of the specified test piece within the detection zone. For explanation of the concept of probability of detection and the tolerance zone, see Annex BB.

3.4314
user coordinate system
coordinate system that may be configured by the user

3.4315
zone with limited detection capability
volume between the detection zone and the front of the sensing device in which the stated detection capability is not achieved

3.4316
stereo base
distance between the entrance pupils of two imaging devices

Note 1 to entry: The expression baseline is often used as synonym for stereo base.

3.4317
position accuracy
accuracy in three dimensions of the position of an object as measured by VBPDST

Addition:

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Abbreviated terms

AIT	Ambient illumination technique
BTP	Black test piece
GB	Grey background
GTP	Grey test piece
lx	Lux
LC	Low contrast
OD	Operating distance
P1	Position 1 of the light source
P2	Position 2 of the light source
PAPT	Pattern projection techniques
PTZ	Tolerance zone related to probability
RRTP	Retro-reflective test piece
STZ	Tolerance zone related to systematic influences
TTC	Typical test condition (test condition for normal operation tests)
TI	Typical illumination (illumination used for normal operation tests)
VBPDST	Vision based protective devices using stereo vision techniques
WTP	White test piece

4 Functional, design and environmental requirements

This clause of Part 1 is applicable except as follows:

4.1 Functional requirements

Replacement:

4.1.2 Sensing function

The detection zone shall begin at the border of the zone with limited detection capability and end at the maximum operating distance (see Figure 2 and Figure 3).

Object(s) in the zone with limited detection capability shall not reduce the detection capability within the detection zone. Any reduction of the detection capability shall be detected and the VBPDST shall go to lock-out condition (see 4.2.2.4).

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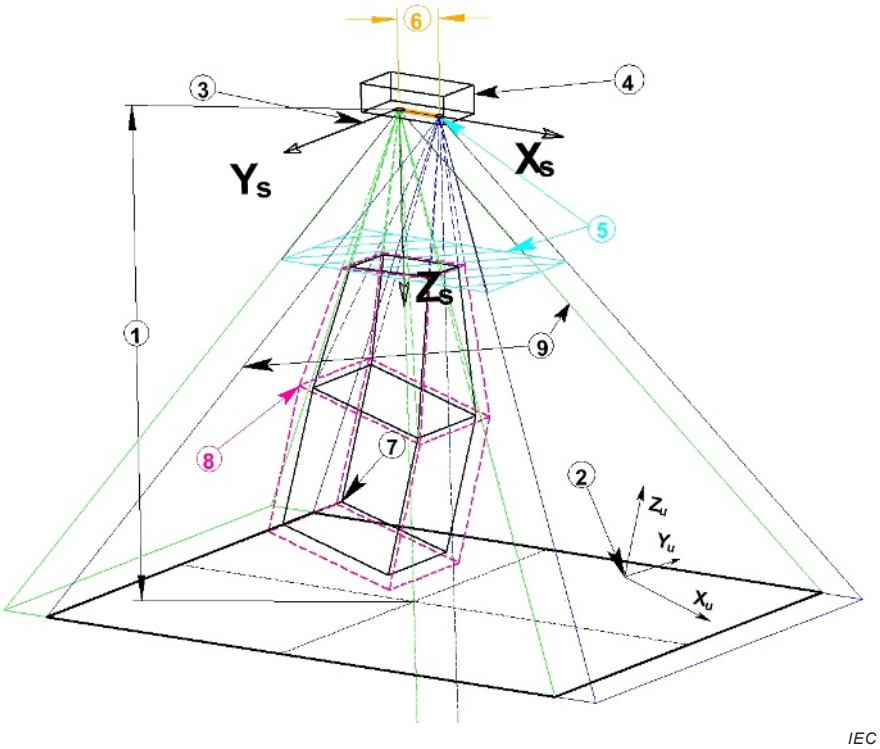

Key

1 - Maximum operating distance	4 - Sensing device	7 - Detection zone
2 - User coordinate system	5 - Zone with limited detection capability	8 - Tolerance zone
3 - Sensing device coordinate system	6 - Stereo base	9 - Stereo field of view

NOTE The figure shows a system with parallel axes and a maximum operating distance on a plane perpendicular to the axes.

Figure 2 – 3D view of a vision based protective device using stereo vision techniques (VBPDST)

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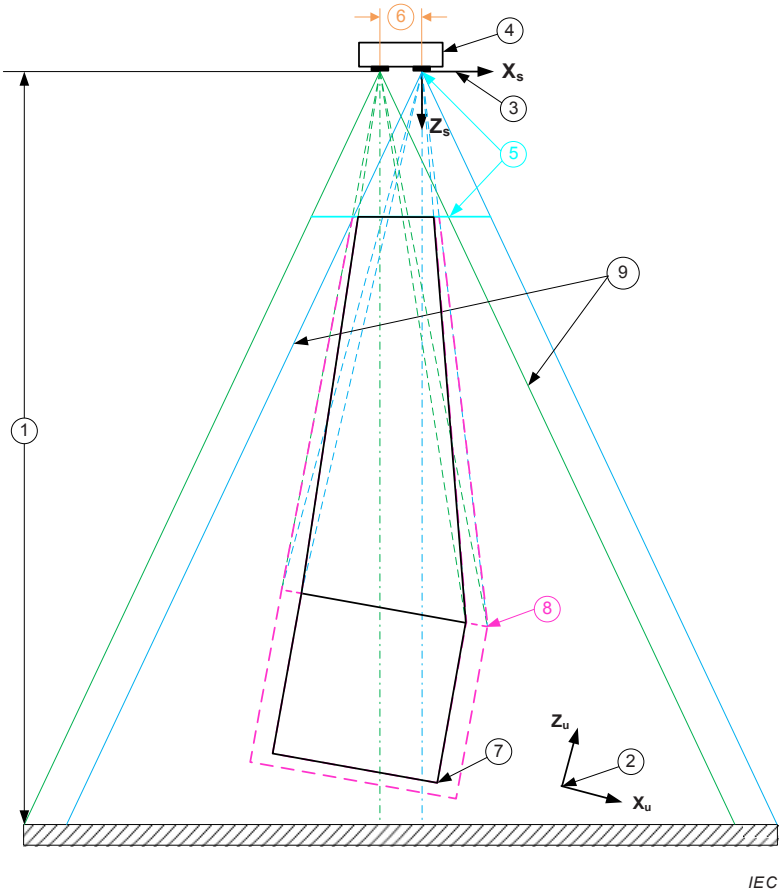

Key

1- Maximum operating distance	4- Sensing device	7- Detection zone
2- User coordinate system	5- Zone with limited detection capability	8- Tolerance zone
3- Sensing device coordinate system	6- Stereo base	9- Stereo field of view

NOTE This figure shows a system with parallel axes and a maximum operating distance on a plane perpendicular to the axes.

Figure 3 – 2D view of a vision based protective device using stereo vision techniques (VBPDST)

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Additional functional requirements:

4.1.2.1 General

The sensing function shall be effective over the detection zone. No adjustment of the detection zone or detection capability shall be possible without the use of a security measure (e.g. key, keyword, or tool).

The VBPDST shall respond by giving appropriate output signal(s) when a test piece is present anywhere within the detection zone whether static or moving with respect to the VBPDST.

The supplier shall specify the limits of detection capability. The supplier shall take into account worst case scenario considering all influences listed in this technical specification including, for example:

– signal-to-noise ratio;
– light intensity in the image in sensor plane (see Figure 1);
– contrast on the image in sensor plane;
– position of the image in sensor plane;

4.1.2.2 Optical performance

The VBPDST shall be designed and constructed to:

a) limit the possibility of malfunction during exposure to extraneous radiation in the range of 400 nm to 1 500 nm;
b) limit the effects of environmental influences (temperature, vibration and bumps, dust, moisture, ambient light, extraneous reflections, changing illumination, shadows on background, background reflectivity);
c) limit the misalignment at which normal operation is possible.

4.1.3 Types of ESPE

Replacement:

In this part of IEC 61496, only a type 3 ESPE is considered. It is the responsibility of the machine supplier and/or the user to prescribe if this type is suitable for a particular application.

The type 3 ESPE shall fulfil the fault detection requirements of 4.2.2.4 of this part of IEC 61496. In normal operation, the output circuit of each of at least two output signal switching devices (OSSDs) of the type 3 ESPE shall go to the OFF-state when the sensing device is actuated, or when the power is removed from the device.

Addition:

4.1.6 Zone with limited detection capability

A zone between the optical window and the beginning of the detection zone is referred to as a zone with limited detection capability. In order to ensure that no hazard can arise in a particular application due to the presence of objects in the zone between the optical window and the detection zone, its dimensions and appropriate information for use shall be provided by the supplier.

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4.2 Design requirements

4.2.2 Fault detection requirements

4.2.2.2 Particular requirements for a type 1 ESPE

This subclause of Part 1 is not applicable.

4.2.2.3 Particular requirements for a type 2 ESPE

This subclause of Part 1 is not applicable.

4.2.2.4 Particular requirements for a type 3 ESPE

Replacement:

A single fault in the sensing device resulting in a complete loss of the stated VBPDST detection capability shall cause the ESPE to go to a lock-out condition within the specified response time.

A single fault resulting in a deterioration of the stated VBPDST detection capability shall cause the ESPE to go to the lock-out condition within a time period of 5 s following the occurrence of that fault.

NOTE Examples of deterioration of the VBPDST detection capability include:

– increase of the minimum detectable object size;

– increase in the minimum detectable contrast;

– decrease of position accuracy.

A single fault resulting in an increase in response time beyond the specified value or preventing at least one OSSD going to the OFF-state shall cause the ESPE to go to a lock-out condition immediately, i.e. within the response time, or immediately upon any of the following demand events where fault detection requires a change in state:

– on actuation of the sensing function;
– on switch off/on;
– on reset of the start interlock or the restart interlock, if provided (see Clauses A.5 and A.6 of IEC 61496-1:2012).

It shall not be possible for the ESPE to achieve a reset from a lock-out condition, for example, by interruption and restoration of the mains power supply or by any other means, when the fault which initiated the lock-out condition is still present.

In cases where a single fault which does not cause a failure to danger of the ESPE is not detected, the occurrence of one additional fault shall not cause a failure to danger.

For verification of this requirement, see 5.3.4.

4.2.2.5 Particular requirements for a type 4 ESPE

This subclause of Part 1 is not applicable.

Additional design requirements:

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4.2.12 Integrity of the VBPDST detection capability

4.2.12.1 General

The design of the VBPDST shall ensure that the detection capability is not degraded below the limits specified by the supplier and in this Technical Specification by any of, but not limited to, the following:

a) low contrast between an object and background on the evaluation images;
b) the position of the object within the detection zone;
c) the number of objects within the detection zone;
d) the size of object(s) within the detection zone;
e) auto-adjustment of optical and electrical characteristics;
f) properties/limitations of optical and electrical components;
g) accuracy of object position in image(s);
h) at the limits of alignment and/or adjustment;
i) ageing of components;
j) performance and limitations of the optical components;
k) component tolerances;
l) changing of internal and external references to ensure the detection capability;
m) environmental conditions specified in 4.3.

If a single fault, which under normal operating conditions (see 5.1.2.1) would not result in a loss of the stated VBPDST detection capability but, when occurring with a combination of the above conditions, would result in such a loss, that fault together with that combination of conditions (as determined to be relevant during the analysis of the design) shall be considered as a single fault and the VBPDST shall respond to such a single fault as required in 4.2.2.4.

4.2.12.2 Object detection at low contrast

At low contrast the test piece shall be detected when the VBPDST is in normal operation.

NOTE A physical contrast results in a difference of intensity that is detected. For more information, see Annex CC.

4.2.12.3 Object detection at high contrast

At high contrast the test piece shall be detected when the VBPDST is in normal operation.

NOTE A high contrast results from a big difference of the diffuse reflectance value and/or lighting variation between the background and the test piece. The contrast could be higher than the dynamic range of the imaging sensor.

4.2.12.4 Minimum detection zone

The supplier shall specify the minimum detection zone(s). The supplier shall take into account worst case conditions including, for example:

– response time;
– minimum diameter of the test piece;
– maximum speed of the test piece.

4.2.12.5 Response time

Objects of the minimum detectable size that are either stationary or moving within the detection zone at any speed up to 1,6 m/s shall be detected by the ESPE within the specified response time. The supplier shall specify the maximum response time. The supplier shall take

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into account worst case conditions including, for example, frame rate, evaluation time, minimum diameter of the test piece, maximum speed of the test piece, number of objects in the detection zone and the values of the minimum detection zone, as well as environmental influences. Where the supplier states that a VBPDST can be used to detect objects moving at speeds greater than 1,6 m/s, the requirements shall be met at any speed up to and including the stated maximum speed.

4.2.12.6 Detection zone(s) and tolerance zone(s)

The supplier shall define values up to 200 mm as the minimum detectable object size of the VBPDST within the detection zone. The minimum detectable object size may be distance dependent.

The test pieces (see 4.2.13) shall be detected with a minimum probability of detection of $1 - 2{,}9 \times 10^{-7}$ throughout the detection zone(s). To achieve this minimum probability of detection, the tolerance zone has to be considered in addition to the detection zone. The tolerance zone depends on position accuracy composed of systematic (STZ) and random influences (PTZ). Even if a measured distance value of a test piece falls into the tolerance zone, this test piece will be determined as detected and the OSSDs shall go to the OFF-state or remain in the OFF-state. If a part of the position error does not result in failure to danger, then it does not need to be included in the tolerance zone.

NOTE 1 Under the assumption that errors are normally distributed, the PTZ will be 5 times the standard deviation of the error distribution (5 sigma).

NOTE 2 Within the tolerance zone there is no requirement for maintaining a minimum probability of detection.

NOTE 3 The dimensions of the tolerance zone in the three axes can be different.

NOTE 4 An example to determine the tolerance zone is given in Annex BB.

The supplier shall specify the tolerance zone(s) and take into account worst-case considerations according to the influences listed in 4.2.12.7.

When using reference markers or parts of the environment such as walls or the floor during setup, errors in determining the correct distance and position of these references shall be taken into account when specifying the tolerance zone(s).

NOTE 5 The dimension of the tolerance zone can be influenced by the method of approach (for example walking, crawling, sliding along a wall). If such information is used to calculate the tolerance zone, then appropriate analysis or tests can be required.

NOTE 6 If the required probability of detection can be satisfied by partial intrusion of an object into the detection zone, then a smaller tolerance zone can be used for safety distance determination. Further details can be found in Annex AA.

4.2.12.7 Position accuracy

When determining the position accuracy, the following systematic and random influences shall be taken into account:

a) the calibration of the sensing device;
b) characteristics of the optical/imaging sensor, such as
   1) the number of pixels and pixel size
   2) signal-to-noise ratio
   3) modulation transfer function of the optics
c) algorithmic influences, such as:
   1) smoothing algorithm
   2) feature based detection algorithm, e.g. edge detection algorithm
   3) template matching

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4) colour sensor and algorithm
5) global algorithms, e.g. cluster algorithm
6) optical flow analysis algorithm
7) object tracking algorithm
8) stereo algorithm

d) synchronization between imaging sensors;
e) characteristics of the test piece;
f) limits of illumination;
g) Ageing and tolerances of components and references.

4.2.12.8 Pattern projection techniques (PAPT)

If pattern projection techniques are used to enhance the contrast in the scene, then the pattern projector shall be considered as part of the VBPDST. This illumination module shall have the capability to project sufficient contrast onto the scene anywhere within the specified detection zone such that the system fulfils the requirements of this Technical Specification. The detection capability shall not be decreased below the limits specified by the supplier by any, but not limited to the following influences:

a) contrast between projected pattern elements;
b) contrast changes within projected pattern elements;
c) size and differentiation of projected pattern elements and number of projected pattern elements used for contrast enhancement;
d) size of pixels and numbers of pixels compared to used projected pattern elements;
e) automatic adaptation of algorithm/routines;
f) size, shape, colour, reflectivity, position and surface structure of object and scene compared to projected pattern;
g) resulting superposition of natural object/scene contrast and contrast produced by pattern projection;
h) position and location of pattern projector.

4.2.12.9 Influence of periodic surface structures on the background

Periodic surface structures on the background shall not lead to a failure to danger.

Periodic surface structures resulting in a complete loss of the stated VBPDST detection capability shall cause the ESPE to go to a lock-out condition within the specified response time.

Periodic surface structures resulting in a deterioration of the stated VBPDST detection capability shall cause the ESPE to go to the lock-out condition within a time period of 5 s following the occurrence of periodic surface structures.

These requirements are verified by the tests of 5.2.1.5.

4.2.13 Test pieces for type testing

4.2.13.1 General

The test pieces shall be provided by the supplier for use in the type tests of Clause 5. They shall be marked with a type reference and identification of the VBPDST with which they are intended to be used.

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