TECHNICAL SPECIFICATION

ISO/TS 19159-1

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Geographic information — Calibration and validation of remote sensing imagery sensors and data —

Part 1:
Optical sensors

Information géographique — Calibration et validation de capteurs de télédétecion —

Partie 1: Capteurs optiques

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Foreword

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The committee responsible for this document is ISO/TC 211, *Geographic information/Geomatics*.

ISO 19159 consists of the following parts, under the general title *Geographic information — Calibration and validation of remote sensing imagery sensors*:

— *Part 1: Optical sensors*

Part 2 is planned to cover laser scanning, also known as light detection and ranging (LIDAR), SAR/InSAR (RADAR) and SONAR (sound). Parts 3 and 4 are planned to cover RADAR (radio detection and ranging) with the subtopics SAR (synthetic aperture radar) and InSAR (interferometric SAR) as well as SONAR (sound detection and ranging) that is applied in hydrography

Introduction

Imaging sensors are one of the major data sources for geographic information. Typical spatial outcomes of the production process are vector maps, Digital Elevation Models, and three-dimensional city models. There are typically two streams of spectral data analysis, that is, the statistical method, which includes image segmentation, and the physics-based method, which relies on characterization of specific spectral absorption features.

In each of the cases, the quality of the end products fully depends on the quality of the measuring instruments that has originally sensed the data. The quality of measuring instruments is determined and documented by calibration.

A calibration is often a costly and time-consuming process. Therefore, a number of different strategies are used that combine longer time intervals between subsequent calibrations with simplified intermediate calibration procedures that bridge the time gap and still guarantee a traceable level of quality. Those intermediate calibrations are called validations in this part of ISO 19159.

This part of ISO 19159 standardizes the calibration of remote sensing imagery sensors and the validation of the calibration information and procedures. It does not address the validation of the data and the derived products.

Many types of imagery sensors exist for remote sensing tasks. Apart from the different technologies, the need for a standardization of the various sensor types has different levels of priority. In order to meet those requirements, ISO 19159 has been split into more than one part. Part 1 covers optical sensors, i.e. airborne photogrammetric cameras and spaceborne optical sensors. Part 2 is intended to cover laser scanning, also known as LIDAR (Light detection and ranging).

Parts 3 and 4 are planned to cover RADAR (radio detection and ranging) with the subtopics SAR (synthetic aperture radar) and InSAR (interferometric SAR) as well as SONAR (sound detection and ranging) that is applied in hydrography.

Geographic information — Calibration and validation of remote sensing imagery sensors and data —

Part 1: Optical sensors

1 Scope

This part of ISO 19159 defines the calibration and validation of airborne and spaceborne remote sensing imagery sensors.

The term “calibration” refers to geometry, radiometry, and spectral, and includes the instrument calibration in a laboratory as well as *in situ* calibration methods.

The validation methods address validation of the calibration information.

This part of ISO 19159 also addresses the associated metadata related to calibration and validation which have not been defined in other geographic information International Standards.

The specified sensors include optical sensors of the frame camera and line camera types (2D CCD scanners).

2 Conformance

This part of ISO 19159 standardizes the service metadata for the calibration procedures of optical remote sensing sensors as well as the associated data types and code lists. Therefore conformance depends on the type of entity declaring conformance.

Mechanisms for the transfer of data are conformant to this part of ISO 19159 if they can be considered to consist of transfer record and type definitions that implement or extend a consistent subset of the object types described within this part of ISO 19159.

Details of the conformance classes are given in the Abstract test suite in Annex A.

3 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable to its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 19115-2:2009, *Geographic information — Metadata — Part 2: Extensions for imagery and gridded data*

ISO/TS 19130:2010, *Geographic information — Imagery sensor models for geopositioning*

4 Terms and definitions

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

4.1
blooming
overflow of an over-saturated signal of one pixel to the neighbouring pixel

4.2
calibration
process of quantitatively defining a system's responses to known, controlled signal inputs

[SOURCE: ISO/TS 19101-2:2008, 4.2]

Note 1 to entry: A calibration is an operation that, under specified conditions, in a first step, establishes a relationship between indications (with associated *measurement* (4.16) uncertainties) and the physical *quantity* (4.27) values (with measurement uncertainties) provided by measurement standards.

4.3
calibration curve
expression of the relation between indication and corresponding measured *quantity* (4.27) value

Note 1 to entry: A calibration curve expresses a one-to-one relation that does not supply a *measurement* (4.16) result as it bears no information about the measurement *uncertainty* (4.38).

[SOURCE: ISO/IEC Guide 99:2007, 4.31]

4.4
calibration validation
process of assessing the validity of parameters

Note 1 to entry: With respect to the general definition of validation the "calibration validation" does only refer to a small set of parameters (attribute values) such as the result of a *sensor* (4.32) calibration.

4.5
correction
compensation for an estimated systematic effect

Note 1 to entry: See ISO/IEC Guide 98-3:2008, 3.2.3, for an explanation of "systematic effect".

Note 2 to entry: The compensation can take different forms, such as an addend or a factor, or can be deduced from a table.

[SOURCE: ISO/IEC Guide 99:2007, 2.53]

4.6
dark current
output current of a photoelectric *detector* (4.9) (or of its cathode) in the absence of incident radiation

Note 1 to entry: For calibration of optical *sensors* (4.32) dark current is measured by the absence of incident optical radiation.

4.7
dark current noise
noise (4.22) of current at the output of a *detector* (4.9), when no optical radiation is sensed

4.8
dark signal non uniformity
DSNU
response of a *detector* (4.9) element if no visible or infrared light is present

Note 1 to entry: This activation is mostly caused by imperfection of the detector.

4.9
detector
<electro-optical> device that generates an output signal in response to an energy input

Note 1 to entry: The energy input may be provided by electro-magnetic radiation. The output may be a measurable and reproducible electrical signal.

[SOURCE: ISO/TS 19130:2010, 4.18, modified]

4.10
ground sampling distance
GSD
linear distance between pixel centres on the ground

Note 1 to entry: GSD is a *measure* (4.15) of one limitation to image *resolution* (4.30), that is, the limitation due to sampling distance on the ground that corresponds to the pixel distances in the image plane.

Note 2 to entry: The GSD is the distance between the centre points of surface elements represented by adjacent elements in the image matrix.

Note 3 to entry: The GSD depends on flying height, terrain height and observation angle.

Note 4 to entry: The GSD can also be named ground sample distance.

Note 5 to entry: This definition also applies for water surfaces.

[SOURCE: ISO/TS 19130:2010, 4.45, modified — Notes 1 to 4 have been added.]

4.11
in situ measurement
direct *measurement* (4.16) of the measurand in its original place

4.12
instantaneous field of view
IFOV
instantaneous region seen by a single *detector* (4.9) element, measured in angular space

[SOURCE: ISO/TS 19130-2:2014, 4.36]

4.13
irradiance
electro-magnetic radiation energy per unit area per unit time

Note 1 to entry: The SI unit is watts per square metre (W/m^2).

4.14
keystone effect
distortion of a projected image caused by a tilt between the image plane and the projection plane resulting in a trapezoidal shaped projection of a rectangular image

4.15
measure
value described using a numeric amount with a scale or using a scalar reference system

Note 1 to entry: When used as a noun, measure is a synonym for physical *quantity* (4.27).

[SOURCE: ISO 19136:2007, 4.1.41]

4.16
measurement
set of operations having the object of determining the value of a *quantity* (4.27)

[SOURCE: ISO/TS 19101-2:2008, 4.20]

4.17
measurement accuracy
accuracy of measurement
accuracy
closeness of agreement between a test result or *measurement* (4.16) result and the true value

Note 1 to entry: The concept “measurement accuracy” is not a *quantity* (4.27) and is not given a numerical quantity value. A measurement is said to be more accurate when it offers a smaller *measurement error* (4.18).

Note 2 to entry: The term "measurement accuracy" should not be used for measurement trueness and the term *measurement precision* (4.19) should not be used for "measurement accuracy", which, however, is related to both these concepts.

Note 3 to entry: "Measurement accuracy" is sometimes understood as closeness of agreement between measured quantity values that are being attributed to the measurand.

[SOURCE: ISO 6709:2008, 4.1, modified — The preferred term is "measurement accuracy" rather than "accuracy" and Notes 1 to 3 have been added.]

4.18
measurement error
error of measurement
error
measured *quantity* (4.27) value minus a reference quantity value

Note 1 to entry: The concept of "measurement error" can be used both

a) when there is a single reference quantity value to refer to, which occurs if a calibration is made by means of a *measurement* (4.16) standard with a measured quantity value having a negligible measurement *uncertainty* (4.38) or if a conventional quantity value is given, in which case the measurement error is known, and

b) if a measurand is supposed to be represented by a unique true quantity value or a set of true quantity values of negligible range, in which case the measurement error is not known.

Note 2 to entry: Measurement error should not be confused with production error or mistake.

[SOURCE: ISO/IEC Guide 99:2007, 2.16]

4.19
measurement precision
precision
closeness of agreement between indications or measured *quantity* (4.27) values obtained by replicate *measurements* (4.16) on the same or similar objects under specified conditions

Note 1 to entry: Measurement precision is usually expressed numerically by measures of imprecision, such as standard deviation, variance, or coefficient of variation under the specified conditions of measurement.

Note 2 to entry: The "specified conditions" can be, for example, repeatability conditions of measurement, intermediate precision conditions of measurement, or reproducibility conditions of measurement (see ISO 5725-3).

Note 3 to entry: Measurement precision is used to define measurement repeatability, intermediate measurement precision, and measurement reproducibility.

Note 4 to entry: Sometimes "measurement precision" is erroneously used to mean *measurement accuracy* (4.17).

[SOURCE: ISO/IEC Guide 99:2007, 2.15]

4.20
metric traceability
property of the result of a *measurement* (4.16) or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties

[SOURCE: ISO/TS 19101-2:2008, 4.23]

4.21
metrological traceability chain
traceability chain
sequence of *measurement* (4.16) standards and calibrations that is used to relate a measurement result to a reference

Note 1 to entry: A metrological traceability chain is defined through a calibration hierarchy.

Note 2 to entry: A metrological traceability chain is used to establish metrological traceability of a measurement result.

Note 3 to entry: A comparison between two measurement standards may be viewed as a calibration if the comparison is used to check and, if necessary, correct the *quantity* (4.27) value and measurement *uncertainty* (4.38) attributed to one of the measurement standards.

[SOURCE: ISO/IEC Guide 99:2007, 2.42]

4.22
noise
unwanted signal which can corrupt the *measurement* (4.16)

Note 1 to entry: Noise is a random fluctuation in a signal disturbing the recognition of a carried information.

[SOURCE: ISO 12718:2008, 2.26]

4.23
pixel response non-uniformity
PRNU
inhomogeneity of the response of the *detectors* (4.9) of a detector array to a uniform activation

4.24
point-spread function
PSF
characteristic response of an imaging system to a high-contrast point target

[SOURCE: IEC 88528-11:2004]

4.25
positional accuracy
closeness of coordinate value to the true or accepted value in a specified reference system

Note 1 to entry: The phrase "absolute accuracy" is sometimes used for this concept to distinguish it from relative positional accuracy. Where the true coordinate value may not be perfectly known, accuracy is normally tested by comparison to available values that can best be accepted as true.

[SOURCE: ISO 19116:2004, 4.20]

4.26
quality assurance
part of quality management focused on providing confidence that quality requirements will be fulfilled

[SOURCE: ISO 9000:2005, 3.2.11]

4.27
quantity
property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference

Note 1 to entry: A reference can be a *measurement* (4.16) unit, a measurement procedure, a reference material, or a combination of such.

Note 2 to entry: Symbols for quantities are given in the ISO 80000 and IEC 80000 series *Quantities and units*. The symbols for quantities are written in italics. A given symbol can indicate different quantities.

Note 3 to entry: A quantity as defined here is a scalar. However, a vector or a tensor, the components of which are quantities, is also considered to be a quantity.

Note 4 to entry: The concept "quantity" may be generically divided into, e.g. "physical quantity", "chemical quantity", and "biological quantity", or "base quantity" and "derived quantity".

[SOURCE: ISO/IEC Guide 99:2007, 1.1, modified — The Notes have been changed.]

4.28
reference standard
measurement (4.16) standard designated for the calibration of other measurement standards for quantities of a given kind in a given organization or at a given location

4.29
remote sensing
collection and interpretation of information about an object without being in physical contact with the object

[SOURCE: ISO/TS 19101-2:2008, 4.33]

4.30
resolution
<imagery> smallest distance between two uniformly illuminated objects that can be separately resolved in an image

Note 1 to entry: This definition refers to the spatial resolution.

Note 2 to entry: In the general case, the resolution determines the possibility to distinguish between separated neighbouring features (objects).

Note 3 to entry: Resolution can also refer to the spectral and the temporal resolution.

[SOURCE: ISO/TS 19130-2:2014, 4.61, modified: Notes 1 to 3 have been added]

4.31
resolution
<sensor> smallest difference between indications of a *sensor* (4.32) that can be meaningfully distinguished

Note 1 to entry: For imagery, *resolution* (4.30) refers to radiometric, spectral, spatial and temporal resolutions.

[SOURCE: ISO/TS 19101-2:2008, 4.34]

4.32
sensor
element of a measuring system that is directly affected by a phenomenon, body, or substance carrying a *quantity* (4.27) to be measured

Note 1 to entry: Active or passive sensors exist. Often two or more sensors are combined to a measuring system.

[SOURCE: ISO/IEC Guide 99:2007, 3.8, modified — The Note has been changed.]

4.33
smile distortion
centre wavelength shift of spectral channels caused by optical distortion

Note 1 to entry: This distortion is often simply called smile.

4.34
spectral resolution
specific wavelength interval within the electromagnetic spectrum

Note 1 to entry: The spectral wavelength interval is the least difference in the radiation wavelengths of two monochromatic radiators of equal intensity that can be distinguished according to a given criterion.

Note 2 to entry: Spectral resolution determines the ability to distinguish between separated adjacent spectral features.

[SOURCE: ISO 19115-2:2009, 4.30, modified: Notes 1 to 2 have been added]

4.35
spectral responsivity
responsivity per unit wavelength interval at a given wavelength

Note 1 to entry: The spectral responsivity is the response of the *sensor* (4.32) with respect to the wavelengths dependent radiance.

Note 2 to entry: The definition is described mathematically in IEC 60050–845. The spectral responsivity is quotient of the *detector* (4.9) output d $Y(\lambda)$ by the monochromatic detector input $dX_e(\lambda) = X_{e,\lambda}(\lambda) \bullet d\lambda$ in the wavelength interval dλ as a function of the wavelength λ

$$s(\lambda) = \frac{dY(\lambda)}{dX_c(\lambda)}$$

[SOURCE: IEC 60050-845]

4.36
standardization
activity of establishing, with regard to actual or potential problems, provisions for common and repeated use, aimed at the achievement of the optimum degree of order in a given context

Note 1 to entry: In particular, the activity consists of the processes of formulating, issuing and implementing standards.

Note 2 to entry: Important benefits of standardization are improvement of the suitability of products, processes and services for their intended purposes, prevention of barriers to trade and facilitation of technological cooperation.

[SOURCE: ISO/IEC Guide 2:2004, 1.1]

4.37
stray light
electromagnetic radiation that has been detected but did not come directly from the *IFOV* (4.12)

Note 1 to entry: Stray light may be reflected light within a telescope.

Note 2 to entry: This definition is valid for the optical portion of the spectrum under observation.

4.38
uncertainty
parameter, associated with the result of *measurement* (4.16), that characterizes the dispersion of values that could reasonably be attributed to the measurand

Note 1 to entry: The parameter may be, for example, a standard deviation (or a given multiple of it), or the half-width of an interval having a stated level of confidence.

Note 2 to entry: Uncertainty of measurement comprises, in general, many components. Some of these components may be evaluated from the statistical distribution of the results of series of measurements and can be characterized by experimental standard deviations. The other components, which can also be characterized by standard deviations, are evaluated from assumed probability distributions based on experience or other information.

Note 3 to entry: It is understood that the result of the measurement is the best estimate of the value of the measurand, and that all components of uncertainty, including those arising from systematic effects, such as components associated with *corrections* (4.5) and *reference standards* (4.28), contribute to the dispersion.

Note 4 to entry: When the quality of accuracy or *precision* (4.19) of measured values, such as coordinates, is to be characterized quantitatively, the quality parameter is an estimate of the uncertainty of the measurement results. Because accuracy is a qualitative concept, one should not use it quantitatively, that is associate numbers with it; numbers should be associated with measures of uncertainty instead.

Note 5 to entry: Measurement uncertainty includes components arising from systematic effects, such as components associated with corrections and the assigned *quantity* (4.27) values of measurement standards, as well as the definitional uncertainty. Sometimes estimated systematic effects are not corrected for but, instead, associated measurement uncertainty components are incorporated

Note 6 to entry: The parameter may be, for example, a standard deviation called standard measurement uncertainty (or a specified multiple of it), or the half-width of an interval, having a stated coverage probability.

Note 7 to entry: Measurement uncertainty comprises, in general, many components. Some of these may be evaluated by Type A evaluation of measurement uncertainty from the statistical distribution of the quantity values from series of measurements and can be characterized by standard deviations. The other components, which may be evaluated by Type B evaluation of measurement uncertainty, can also be characterized by standard deviations, evaluated from probability density functions based on experience or other information.

Note 8 to entry: In general, for a given set of information, it is understood that the measurement uncertainty is associated with a stated quality value attributed to the measurand. A modification of this value results in a modification of the associated uncertainty.

[SOURCE: ISO 19116:2004, 4.26]

4.39
validation
process of assessing, by independent means, the quality of the data products derived from the system outputs

Note 1 to entry: In this part of ISO 19159, the term validation is used in a limited sense and only relates to the validation of calibration data in order to control their change over time.

[SOURCE: ISO/TS 19101-2:2008, 4.41]

4.40
verification
provision of objective evidence that a given item fulfils specified requirements

Note 1 to entry: When applicable, *measurement* (4.16)*uncertainty* (4.38) should be taken into consideration.

Note 2 to entry: The item may be, e.g. a process, measurement procedure, material, compound, or measuring system.

Note 3 to entry: The specified requirements may be, e.g. that a manufacturer's specifications are met.

Note 4 to entry: Verification should not be confused with calibration. Not every verification is a *validation* (4.39).

[SOURCE: ISO/IEC Guide 99:2007, 2.44, modified — Note 6 has been deleted.]

4.41
vicarious calibration
post-launch calibration of *sensors* (4.32) that make use of natural or artificial sites on the surface of the Earth

5 Abbreviated terms and symbols

5.1 Abbreviated terms

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer [METI (Japan); NASA]
BRDF	Bi-directional reflectance distribution function
CA	Calibration and validation
CalVal	Calibration and validation
CCD	Charge coupled device
CEOS	Committee on Earth Observation Satellites

CEOS WGCV	Committee on Earth Observation Satellites Working Group Calibration Validation
ENVISAT	Environmental Satellite
EO	Earth observation
ERS	European Remote Sensing Satellite (ESA)
ESA	European Space Agency
FOV	Field-of-view
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GMES	Global monitoring earth system
GPS	Global positioning system
GS	Ground segment
GUM	ISO Guide to the expression of uncertainty in measurement
IEEE	Institute of Electrical and Electronics Engineers
METI	Ministry of Economy, Trade and Industry, Japan
MIR	Mid infrared
MTF	Modulation transfer function
NASA	US National Aeronautic and Space Administration
NIR	Near infrared (spectral region)
QA	Quality assurance
QA4EO	Quality assurance framework for earth observation
RMSE	Root mean square error
RTC	Radiative transfer code
SAA	Solar azimuth angle
SMAC	Simultaneous multiframe analytical calibration
SWIR	Shortwave infrared
SZA	Solar zenith angle
TIR	Thermal infrared
TOA	Top of the atmosphere
VAA	View azimuth angle
VIM	International Vocabulary of Metrology
VIS	Visible
VZA	View zenith angle

5.2 Symbols

Θ_s	Solar angle
$E_s(\lambda)$	Solar irradiance at top of the atmosphere
hc / λ	Photon elementary energy
$T_g(\lambda, \mu_s)$	Gaseous transmittance of the downward path
$T_{atm}(\lambda, \mu)$	Scattering transmittance for the downward path, black ocean and no Fresnel reflection
$S_{atm}(\lambda)$	Spherical albedo
$\rho_w(\lambda)$	Lambertian surface reflectance (water body + foam)

5.3 Variable names of the Jacobsen model

BSXU	x-value of the size of the effectively used original-CCD-size of the UltraCam
BSYU	y-value of the size of the effectively used original-CCD-size of the UltraCam
FACR	r' (distance from image centre) in a camera head (original image)
FACRS	x-component for an additional parameter
FACTS	y-component for an additional parameter
FACRX	x-component for a camera head
FACRY	y-component for a camera head
RO	r' (distance from image centre) in the virtual image
RSING	r' (distance from image centre) in a camera head (original image)
WR	viewing direction in the virtual image [tan]
WTX	x-component of image centre of an image of a camera head (original image) [tan]
WTY	y-component of image centre of an image of a camera head (original image) [tan]
WX	x-component of the viewing direction in the virtual image
WY	y-component of the viewing direction in the virtual image

A camera head is the part of a multihead camera where the original image is taken (6.2.8).

5.4 Conventions

Some of the classes and attributes are defined in other geographic information International Standards. Those classes and attributes are identified by one of the following two-character codes.

CA = This part of ISO 19159

CI = ISO 19115-1

MD = ISO 19115-1

MI = ISO 19115-2

SD = ISO/TS 19130

6 Calibration

6.1 Project

6.1.1 General

This part of ISO 19159 standardizes the calibration of remote sensing imagery sensors and the validation of the calibration information. The ISO 19159 series is split into more than one part, each of them addressing a specific sensor type. This part of ISO 19159 addresses optical sensors i.e. airborne and spaceborne cameras. They include digital frame cameras that take a two-dimensional image as a whole, line cameras which apply the pushbroom or whiskbroom principle as well as sensors that are capable of recording electromagnetic radiation of the infrared spectrum such as thermal, multispectral, and hyperspectral cameras.

All measures of this part of ISO 19159 related to positional accuracy lead to quantitative results according to ISO 19157 and ISO 19115-1.

Figure 1 depicts a package diagram that shows all intended parts of ISO 19159 at the time of publication of this part of ISO 19159.

The CalibrationValidation package represents the top level with only a little additional information.

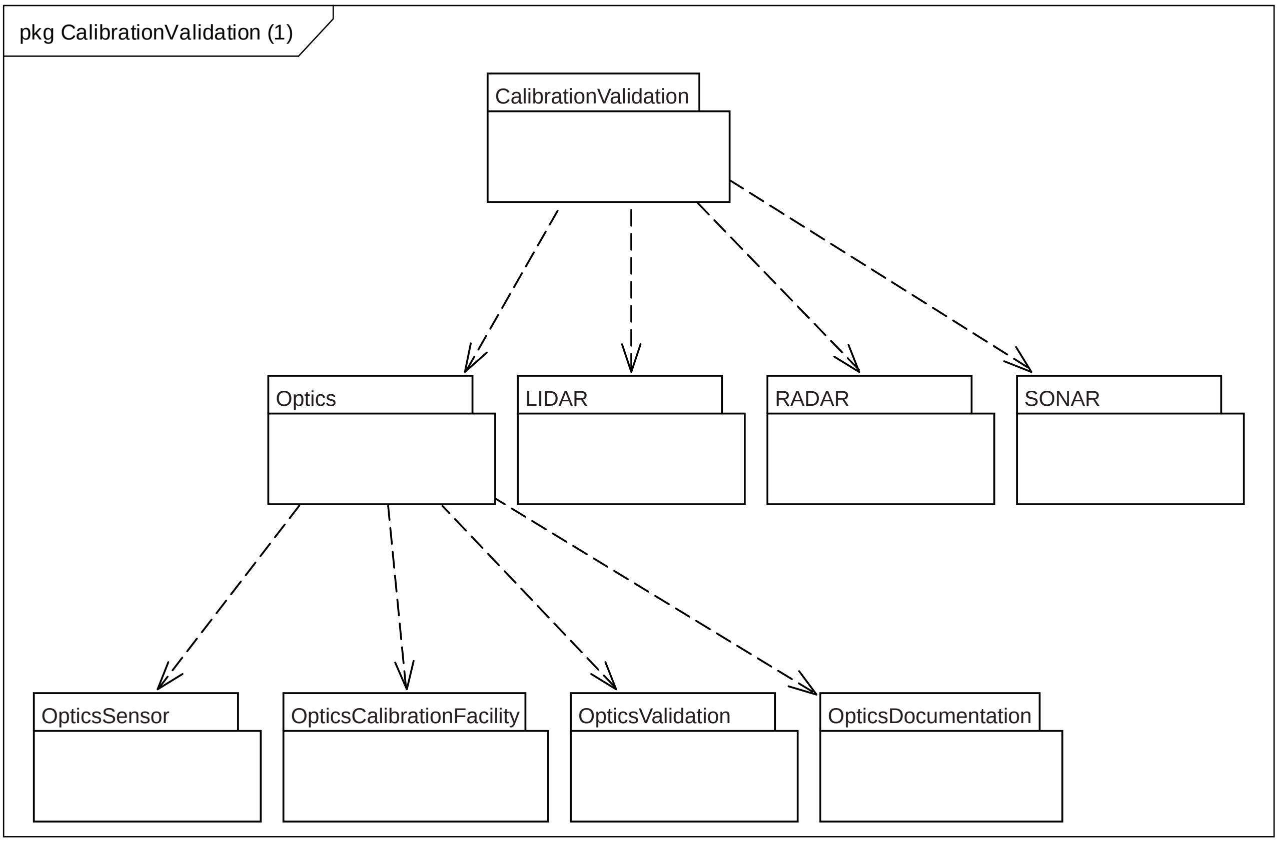


Figure 1 — Package diagram of the package CalibrationValidation

The global settings of ISO 19159 (all parts) are explained in 6.1.2 to 6.1.5. Figure 2 depicts the top-level class diagram of ISO 19159 (all parts). The specialization for CA_OpticalSensors is shown in Figure 3.

The Optics package and its subordinate packages cover the content of this part of ISO 19159. The LIDAR, RADAR and SONAR packages show the titles of the intended additional parts of ISO 19159 (all parts).

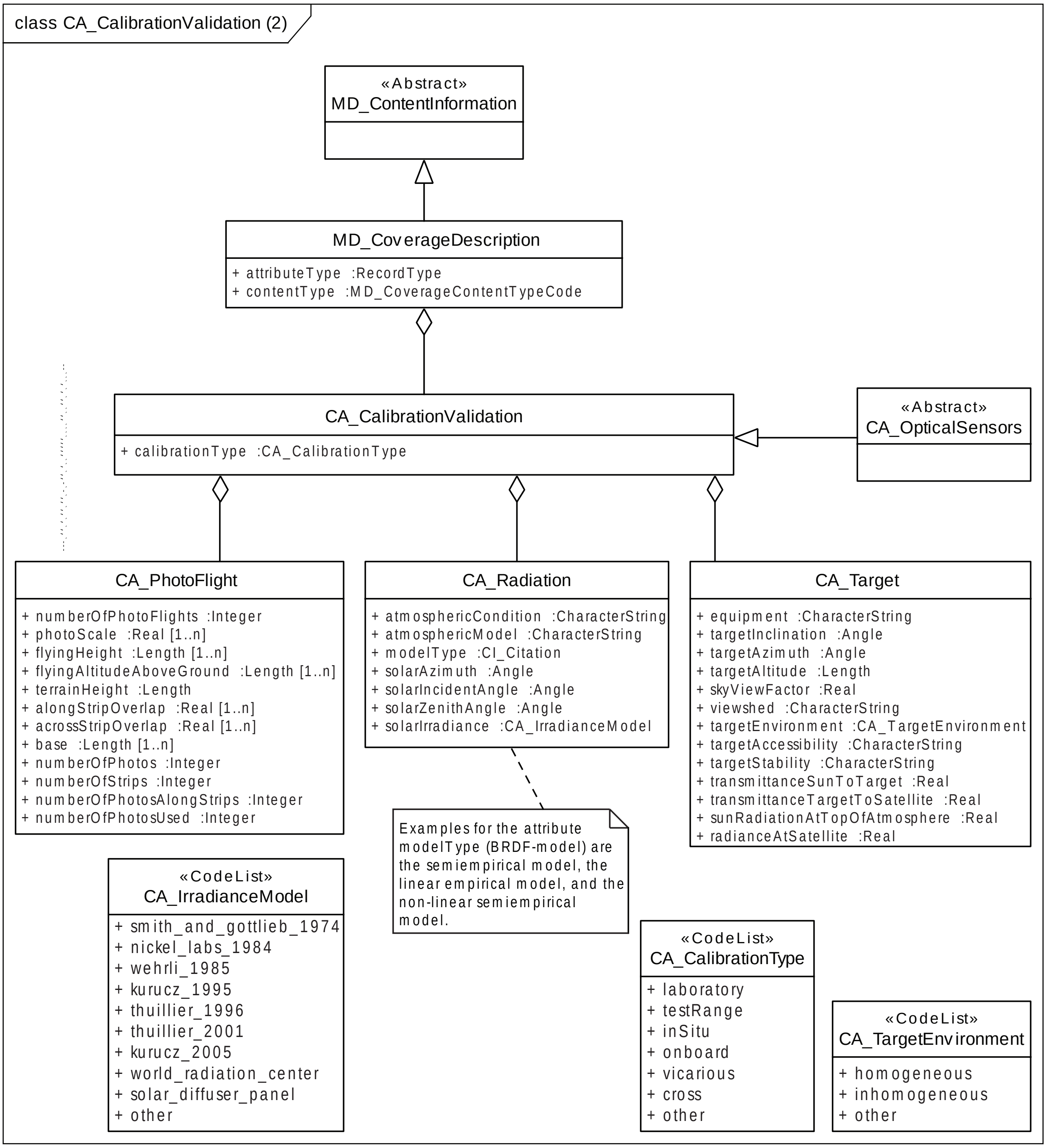


Figure 2 — Top-level class diagram of ISO 19159 (all parts)

The classes and the attributes are explained in detail in Annex B.

6.1.2 CA_CalibrationValidation

The class CA_CalibrationValidation has one attribute that characterizes the calibration process. The attribute has the name calibrationType and the code list CA_CalibrationType.

6.1.3 CA_PhotoFlight

The class CA_PhotoFlight has all information about the photo flight that was made to derive the calibration results from. The length *n* of each array denotes the number of images in the project.

The attributes numberOfPhotoFlights denotes the quantity of photo flights that are taken for performing the calibration. The data type is Integer.

The attribute photoScale denotes the rounded average photo scale of the calibration project. The data type is Real.

The attributes flyingHeight and flyingAltitudeAboveGround denote the average height of the sensor platform above the reference height plane and above the ground. The data type is Length in both cases.

The attribute terrainHeight denotes the average height of the terrain where the calibration is performed. The terrain height is modelled as one value because it is an aggregate value which is often for information purposes or as an approximate value. The data type is Length.

The attributes alongStripOverlap and acrossStripOverlap denote the approximate values for the along strip and the across strip overlap of the photogrammetric block. The data type of the attribute values is Real.

The attribute base denotes the approximate distance between two neighbouring photos. The data type is Length.

The attributes numberOfPhotos, numberOfStrips, numberOfPhotosAlongStrip, and numberOfPhotosUsed denote quantities, i.e. the total number of photos in the photogrammetric block, the total number of strips, the number of photos in the along strip direction, and the number of photos used for processing the calibration respectively. The data type is Integer in all cases.

6.1.4 CA_Radiation

The class CA_Radiation has all information that is necessary to describe the radiative environment during the calibration process.

The attribute solarZenithAngle defines the angle from the zenith towards the sun.

The attribute solarAzimuth defines the horizontal angle to the sun counted counterclockwise from North.

The attribute atmosphericCondition allows for a general description of the status of the atmosphere during the calibration. The data type is CharacterString.

The attribute atmosphericModel states the atmospheric model that is applied in the calibration process. The attribute has the data type CharacterString.

Examples of character strings defining the attribute are 6sv1.1, acorn, actor, atrem(HyspIRI L2), disort, flash, lowtran, modtran4, modtran5, sbdart, smac (SPOT VEGETATION L2), and tafkaa.

The attribute modelType states the BRDF (Bi-directional Reflectance Distribution Function) model that is applied in the calibration process. The data type is CI_Citation. Examples of the model type are linear semiempirical model, linear empirical model, and nonlinear semiempirical model. Normally the citation will contain a reference to the scientific literature describing the model.

The attribute solarIncidentAngle defines the angle which is calculated from solar zenith angle, solar elevation angle, target azimuth, and the target Inclination.

The attribute solarIrradiance defines the irradiance of the sun. The attribute has the data type CA_IrradianceModel.

6.1.5 CA_Target

The class CA_Target has all information necessary to describe the targets used during the calibration process.

The attribute equipment is a character string that allows description of additional equipment, for example measurement instruments.

The attribute targetInclination defines the inclination (slope) of a ground target. The data type is Angle.

The attribute targetAzimuth defines the azimuth of the steepest inclination of the ground target. The data type is Angle.

The attribute targetAltitude defines the ground elevation of the target. This attribute does not regard vegetation and man-made objects. The data type is Length.

The attribute skyViewFactor defines the portion of the sky that is visible from the ground target. The data type is Real.

The attribute viewshed defines the area that is visible from a fixed vantage point. The attribute value is a name of a file that provides a two-dimensional representation of the viewshed. The data type is CharacterString.

The attribute targetEnvironment characterizes the environment of target, namely homogeneous or inhomogeneous. The data type is CA_TargetEnvironment.

The attribute targetAccessibility describes the accessibility of the target primarily regarding road condition and eventual seasonal changes. The data type is CharacterString.

The attribute targetStability describes the mechanical stability of the target depending on weather conditions like humidity, heat, and wind. The data type is CharacterString.

The attribute transmittanceSunToTarget describes the amount of radiation transmitted from the sun to a target on Earth measured in a part of one hundred. The data type is Real.

The attribute transmittanceTargetToSatellite describes the amount of radiation transmitted from a target on Earth to the satellite measured in a part of one hundred. The data type is Real.

The attribute sunRadiationAtTopOfAtmosphere describes the amount of radiation transmitted from the sun to the top of the atmosphere of Earth measured in a part of one hundred. The data type is Real.

The attribute radianceAtSatellite describes the amount of radiation received at the satellite measured in a part of one hundred. The data type is Real.

6.1.6 CA_OpticalSensors

Figure 3 depicts the top-level class diagram for the calibration of optical sensors (this part of ISO 19159). Details of the geometric calibration are shown in Figures 4 and 5, of the radiometric calibration in Figures 6, 7, 8 and 9, of the geometric calibration facility in Figures 10, 11 and 12, of radiometric calibration facility in Figure 13, and of validation in Figure 14.

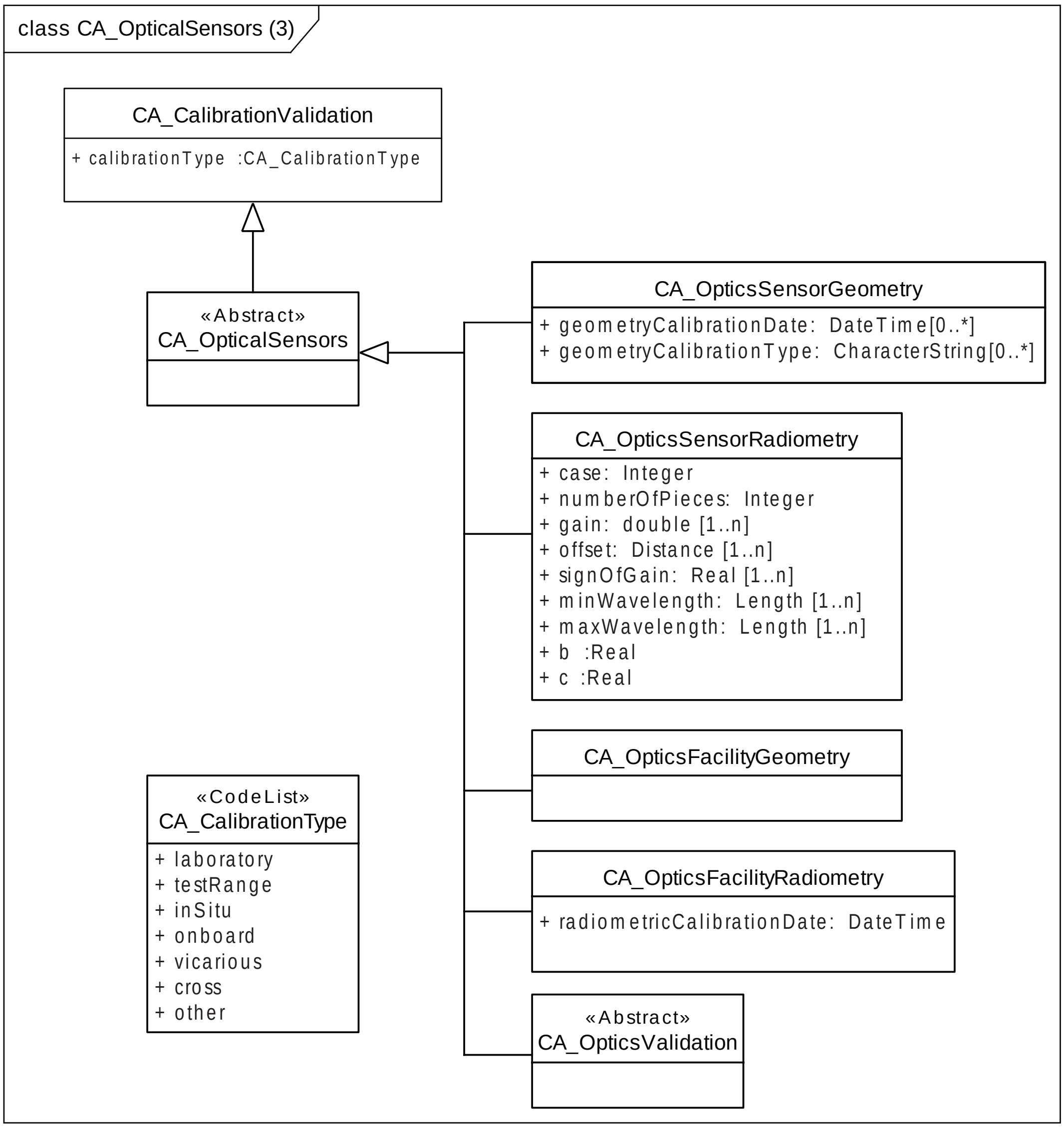


Figure 3 — Class diagram of CA_OpticalSensors and its subordinate classes

The class CA_OpticalSensors has five subclasses that contain the attributes of the calibration of optical sensors. Those five classes are named CA_OpticsSensorGeometry (6.2), CA_OpticsSensorRadiometry (6.3), CA_OpticsFacilityGeometry (6.4), CA_OpticsFacilityRadiometry (6.5), and CA_OpticsValidation (6.6).

The class CA_OpticsSensorGeometry covers all aspects of the sensor geometry. Its subordinate class InteriorOrientation contains all parameters that describe the geometry of the optical sensor. This part of ISO 19159 provides a broad approach to distortion models.

The class CA_OpticsSensorRadiometry contains all sensor-related parameters which characterize the spectral performance of the sensor and which are essential for a controlled transfer from recorded Digital Numbers (DN) to at-aperture radiances and if the atmosphere is sufficiently known to object radiances.

The class CA_OpticsFacilityGeometry contains all data related to calibration laboratories and their equipment and test fields. Those test fields may be installed as a part of a laboratory or outside.

The class CA_OpticsFacilityRadiometry contains all data related to laboratory equipment and test field installations.

The class CA_OpticsValidation covers the parameters for performing a calibration validation of a geometric and a radiometric sensor calibration.

6.1.7 CA_CalibrationType

The code list CA_CalibrationType is a code list that specifies seven types of calibration: laboratory, testRange, inSitu, onboard, vicarious, cross, and other. This code list is a data type of the class CA_CalibrationValidation.

6.1.8 CA_TargetEnvironment

The class CA_TargetEnvironment is a code list that has the codes homogeneous, inhomogeneous, and other.

6.1.9 CA_IrradianceModel

The class CA_IrradianceModel is a code list that has the codes smith_and_gottlieb_1974, nickel_labs_1984, wehrli_1985, kurucz_1995, thuillier_1996, thuillier_2001, kurucz_2005, world_radiation_center, solar_diffuser_panel and other.

6.2 Package OpticsSensor, Geometry

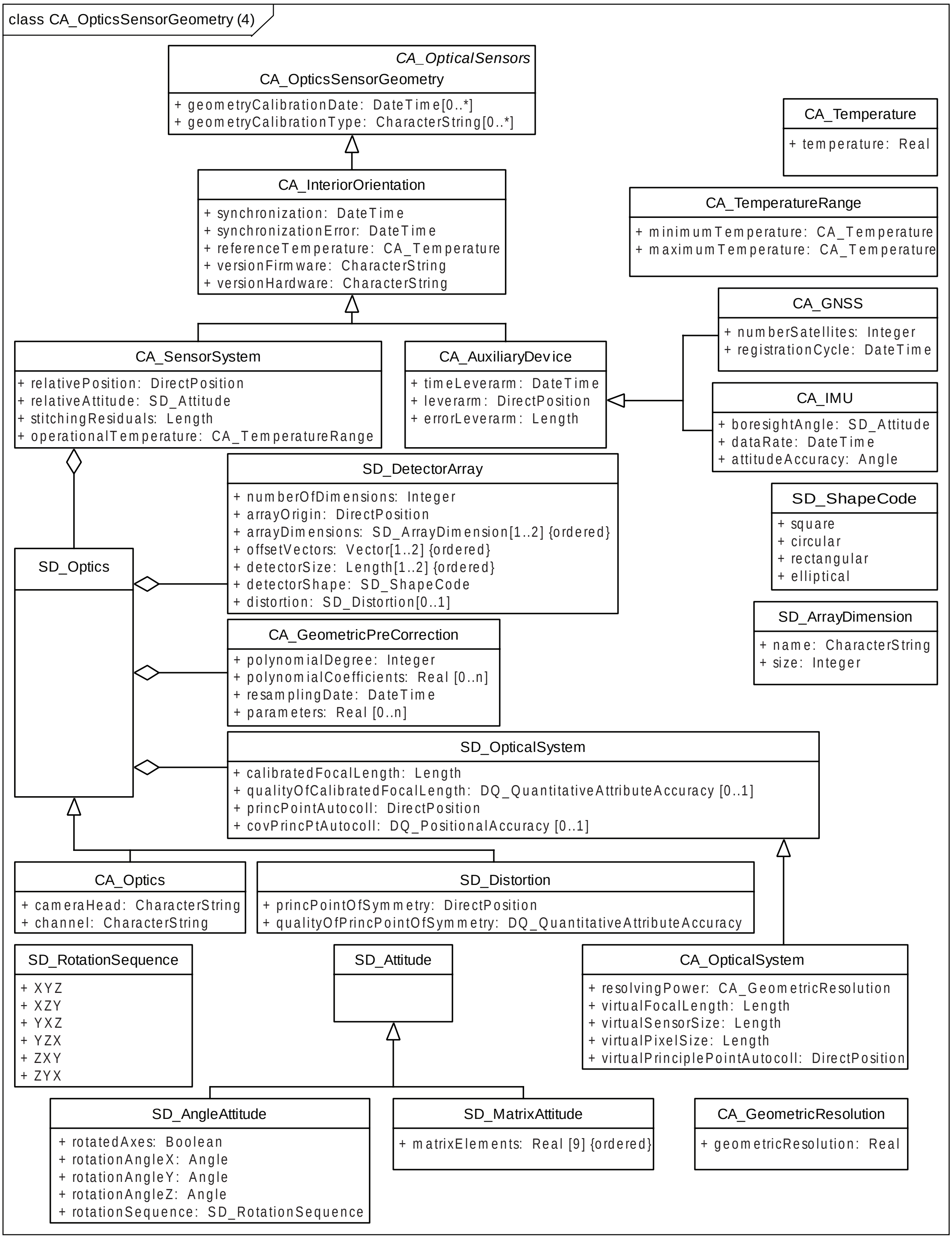
6.2.1 General

The package OpticalSensors addresses all sensors that record the sensed data as an image which is projected at a detector where it is recorded. This package includes aerial and spaceborne cameras, multispectral and thermal cameras, as well as hyperspectral sensors.

The InteriorOrientation defines the details of the geometry of the sensor system relevant for a geometric calibration of this system. The package has two parts, the sensor system and auxiliary devices, which are the Global Navigation Satellite System (GNSS) and Inertial Measurement Unit (IMU). The part sensor system specializes in the subpart optics which stands for optical cameras.

The definition of metadata for distortion is partly in ISO/TS 19130. This part of ISO 19159 provides full reference to the definitions in ISO/TS 19130.

The Figure 4 depicts the class diagram for geometry of the package OpticsSensor apart from distortion. The distortion is shown in Figure 5.



NOTE The classes regarding distortion are excluded and are shown in Figure 5. The classes SD_Attitude, SD_RotationSequence, SD_AngleAttitude, and SD_MatrixAttitude are described in ISO/TS 19130:2010.

Figure 4 — Class diagram of the geometry of the package OpticsSensor

6.2.2 CA_OpticsSensorGeometry

The class CA_OpticsSensorGeometry contains all information that is valid for the entire geometric calibration.

The attribute geometryCalibrationDate defines the time when the calibration was performed.

The attribute geometryCalibrationType is a free text that allows a more detailed explanation of the type defined with CA_CalibrationType.

6.2.3 CA_InteriorOrientation

The class CA_InteriorOrientation has all information that is valid for the sensor systems and the auxiliary devices alike.

The attribute synchronization defines the time between two pulses for the synchronization of the work of the attached components.

The attribute synchronizationError defines the error of the attribute synchronization.

The attribute referenceTemperature defines the temperature for which the calibration is performed.

The attributes versionFirmware and versionHardware are reserved for notes about the versions.

6.2.4 CA_SensorSystem

The class CA_SensorSystem defines the details of a multihead sensors system.

The attribute relativePosition holds the position of the origin of the coordinate system of a camera head in relation to the coordinate system of the sensor system.

The attribute relativeAttitude holds the rotation of the coordinate system of a camera head in relation to the coordinate system of the sensor system.

The attribute stitchingResiduals holds the geometric error remaining after stitching the multi camera-head images to one large image.

The attribute operationalTemperature hold the temperature range for which the calibration is valid.

6.2.5 SD_Optics

The class SD_Optics is defined in ISO/TS 19130 and functions as the aggregated class of three other classes that provide details about the cameras for visible and infrared light, multispectral sensors, hyperspectral sensors, and thermal cameras.

6.2.6 CA_Optics

The class CA_Optics has all information necessary to characterize the optical sensor system (camera) that is not defined in the class SD_Optics of ISO/TS 19130. The class is shown in Figure 4.

The attribute cameraHead allows for a description of the respective camera head. The data type is CharacterString

The attribute channel allows for a description of the available spectral channels. The data type is CharacterString

Figure 5 provides the details related to the class SD_Distortion which is defined in ISO/TS 19130.

6.2.7 SD_OpticalSystem

The class SD_OpticalSystem is defined in ISO/TS 19130 and has information about the calibrated focal length (attribute calibratedFocalLength), the principle point of autocollimation (attribute princPointAutocoll), and their positional quality (attributes qualityOfCalibratedFocalLength and covPrincPtAutocoll).

The calibrated focal length is a computed value. It is similar to the physical focal length but it compensates deficiencies of the optical system, mostly distortion. The calibrated focal length does not eliminate those influences but minimizes their absolute value.

6.2.8 CA_OpticalSystem

The class CA_OpticalSystem has all information of an optical sensor system that is necessary for the geometric calibration and that is not defined in ISO/TS 19130.

The attribute resolvingPower defines the resolving power of the optical system.

The attribute virtualFocalLength defines the computed focal length of a camera system with two or more camera heads. Several digital photogrammetric cameras consist of two of more separate cameras, often called camera-heads, which are firmly attached by a robust frame. Before delivery the separate images are resampled to a homogeneous large image. This large image is equipped with one focal length that approximates the joint image geometry of the two or more original images. This focal length is named the virtual focal length.

The attribute virtualSensorSize defines the computed full sensor size of a camera system with two or more camera heads.

The attribute virtualPixelSize defines the computed pixel size of a camera system with two or more camera heads.

The attribute virtualPrinciplePointAutocoll defines the computed principle point of autocollimation of a camera system with two or more camera heads.

6.2.9 SD_DetectorArray

The class SD_DetectorArray is defined in ISO/TS 19130 and has information about the dimensions and shapes of the detector array.

The attribute numberOfDimensions defines the number of dimensions of the detector array.

The attribute arrayOrigin defines position of the origin of the detector array coordinate system in external coordinate system.

The attribute arrayDimensions defines the names and sizes of the dimensions of the detector array.

The attribute offsetVectors [1..2] defines displacement between origin of the detector array coordinate system and the location of the first detector in the detector array.

The attribute detectorSize [1..2] defines size of a detector in a detector array dimension specified by detectorDimensionName.

The attribute detectorShape defines the shape of a detector.

The attribute distortion defines the distortion of the detector array.

6.2.10 CA_GeometricPreCorrection

The class CA_GeometricPreCorrection has all information about the geometric modification of the image data during the processing from the status raw-data to the status first original.

The attribute polynomialDegree defines the power of the polynomial (u).

The attribute polynomialCoefficients [0..n] defines the coefficients of the polynomial.

The attribute resamplingDate defines the time of processing.

The attribute parameters [0..n] defines all other involved parameters.

6.2.11 CA_AuxiliaryDevice

The class CA_AuxiliaryDevice is the superclass for CA_GNSS and CA_IMU. GNSS and IMU are auxiliary devices for the measurement of position and attitude of moving platforms, e.g. airplanes.

The attribute timeLeverarm defines the time when the leverarm was calibrated. The data type is DateTime.

The attribute leverarm defines the position-vector from the GNSS-reference point to the reference point of the sensor system, e.g. the projection centre of the camera, in the Coordinate Reference System of the platform. The data type of the leverarm is DirectPosition.

The attribute errorLeverarm defines the error of the leverarm. The data type is Length.

6.2.12 CA_GNSS

The class CA_GNSS has all information about the satellite navigation that is relevant for the calibration. A GNSS provides 3D position information based on electronic distance measurements to four and more satellites.

The attributes numberSatellites defines the minimum number of satellites that is necessary for performing a calibration measurement. The attribute is Integer.

The attribute registrationCycle defines the longest allowed temporal interval between two position measurements made by the GNSS. The attribute is DateTime.

6.2.13 CA_IMU

The class CA_IMU has all information about the Inertial Measurement Unit (IMU) that is relevant for the calibration. An IMU provides the three attitude angles of a body relative to an initial orientation in space.

NOTE 1 The angles are updated in intervals of a millisecond and less.

The attribute boresightAngle defines the three angles that define the rotation between the coordinate reference system of the sensor system, e.g. the camera, and the coordinate reference system of the IMU:

$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = R_b \begin{pmatrix} x_{imu} \\ y_{imu} \\ z_{imu} \end{pmatrix} \quad (1)$$

with

$$R_b = \begin{pmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{pmatrix} \quad (2)$$

where

r_{11} = cosφ * cosκ

r_{12} = - cosφ * sinκ

r_{13} = sinφ

r_{21} = cosω * sinκ + sinω * sinφ * cosκ

r_{22} = cosω * cosκ - sinω * sinφ * sinκ

r_{23} = - sinω * cosφ

r_{31} = sinω * sinκ - cosω * sinφ * cosκ

r_{32} = sinω * cosκ + cosω * sinφ * sinκ

r_{33} = cosω * cosφ

where

x', y', z'	is the point vector in the coordinate reference system of the sensor system;
R_b	is the rotation matrix from the IMU to the sensor system;
$x_{imu}, y_{imu}, z_{imu}$	is the point vector in the coordinate reference system of the IMU;
ω, φ, κ	are the attitude angles.

The attribute dataRate defines the temporal interval between two registrations.

The attribute attitudeAccuracy defines the quality of an angular measurement.

NOTE 2 The attitude accuracy decreases over time.

6.2.14 CA_TemperatureRange

The class CA_TemperatureRange is a data type. It has the attributes minimumTemperature and maximumTemperature.

6.2.15 CA_Temperature

The class CA_Temperature is a data type that defines a temperature. Its attribute temperature has the data type Real.

6.2.16 CA_GeometricResolution

The class CA_GeometricResolution is a data type that defines the geometric resolution counted in line-pairs per length-unit [1/Length]. Its attribute geometricResolution has the data type Real.

6.2.17 SD_ShapeCode

The class SD_ShapeCode is a code list that has the codes square, circular, rectangular, and elliptical. Those codes are used to describe the shape of the detector elements of a detector array.

6.2.18 SD_ArrayDimension

The class SD_ArrayDimension is a data type that names and defines the dimension of a detector array. The attributes are termed name and size.

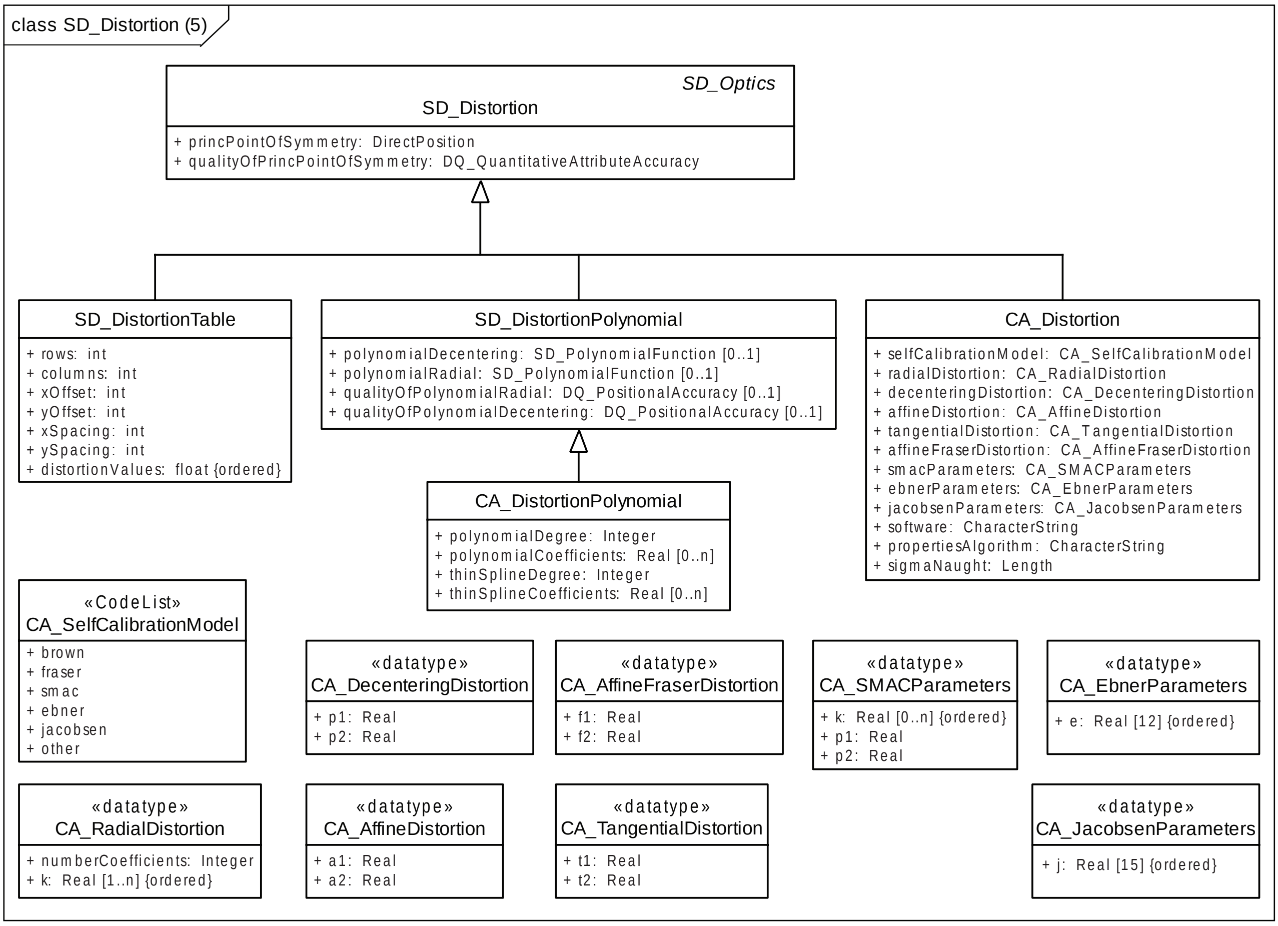


Figure 5 — Class diagram of class SD_Distortion

6.2.19 SD_Distortion

The class SD_Distortion defined in ISO/TS 19130 is the superclass of the classes SD_DistortionTable, SD_DistortionPolynomial, and CA_Distortion, and has information about the principle point of symmetry (attribute princPointOfSymmetry) and the positional quality (attribute qualityOfPrincPointOfSymmetry).

6.2.20 SD_DistortionTable

The class SD_DistortionTable provides distortion information in a tabular form and has been defined in ISO/TS 19130.

The attributes rows and columns define the rows and columns of the distortion table.

The attributes xOffset and yOffset define the image column number and row number corresponding to the first cell in the table.

The attributes xSpacing and ySpacing define the number of columns and the number of rows in the image corresponding to an interval of one table column respective of one of the table rows.

The attribute distortionValues is an array of values describing image distortion.

6.2.21 SD_DistortionPolynomial

The class SD_DistortionPolynomial defines the distortion described using a polynomial.

The attribute polynomialDecentering defines a polynomial that describes decentering distortion.

The attribute polynomialRadial defines a polynomial that describes radially symmetrical distortion.

The attribute qualityOfPolynomialRadial defines the covariance of the polynomial coefficients for radial distortion.

The attribute qualityOfPolynomialDecentring defines the covariance of the polynomial coefficients for decentering distortion.

6.2.22 CA_DistortionPolynomial

The class CA_DistortionPolynomial has all information about the polynomial distortion model that is not defined in the class SD_DistortionPolynomial of ISO/TS 19130.

The attribute polynomialDegree defines the polynomial degree (u) (data type Integer) and the attribute polynomialCoefficients[0..n] defines the coefficients of this polynomial (data type Real).

The relation between u and n is

n = (u+1)(u+2), e.g. if u = 2 then n = 12

The attribute thinSplineDegree defines the thin spline degree (u) (data type Integer) and the attribute thinSplineCoefficients [0..n] defines the coefficients of this thin spline[25] (data type Real).

6.2.23 CA_Distortion

The class CA_Distortion has all distortion information necessary for the geometric calibration of an optical camera that is not covered by ISO/TS 19130.

This part of ISO 19159 covers the following models:

— Brown model

— Fraser model

— SMAC model

— Ebner model

— Jacobsen model

These models are explained in Annex C.

The attribute selfCalibrationModel sets the applied self-calibration model. The value none means that no such model is used.

The attributes radialDistortion, decenteringDistortion, affineDistortion, tangentialDistortion, affineFraserDistortion, smacParameters, ebnerParameters, and jacobsenParameters define the parameters related to those models. Table 1 explains the full relation:

Table 1 — Parameters of the self-calibration models

	Brown	Fraser	SMAC	Ebner	Jacobsen
radial distortion	K_1, K_2, K_3	K_1, K_2, K_3	K_0, K_1, K_2, K_3, …, K_i		
decentering distortion			P_1, P_2		
tangential distortion	T_1, T_2	T_1, T_2			
affine distortion	A_1, A_2				
affine fraser distortion		F_1, F_2			
ebner parameters				$e_1 - e_{12}$	
jacobsen parameters					$j_1 - j_{15}$

The attribute software denotes the name of the software product applied for the calibration processing.

The attribute propertiesAlgorithm denotes the name and the properties of the algorithm that is programmed in the software. The data type is CharacterString.

The attribute sigmaNaught contains the overall error of the calibration processing. The data type is Length.

6.2.24 CA_SelfCalibrationModel

The class CA_SelfCalibrationModel is a code list with the values brown, fraser, smac, ebner, jacobsen, none and other. The codes denote the applied self-calibration model.

6.2.25 CA_RadialDistortion

The class CA_RadialDistortion is a data type with the K-values for describing the radial distortion. The Brown- and the Fraser-model use the values K_1, K_2, and K_3. The SMAC-model uses the values K_0, K_1, K_2, K_3, and eventually higher orders too. A full explanation is provided in Annex C.

6.2.26 CA_DecenteringDistortion

The class CA_DecenteringDistortion is a data type with the P-values for describing the decentering distortion of the SMAC-model. A full explanation is provided in C.4.

6.2.27 CA_AffineDistortion

The class CA_AffineDistortion is a data type with the A-values for describing the affine distortion of the Brown-model. A full explanation is provided in C.2.

6.2.28 CA_TangentialDistortion

The class CA_TangentialDistortion is a data type with the T-values for describing the tangential distortion of the Brown- and the Fraser-model. A full explanation is provided in C.3.

6.2.29 CA_AffineFraserDistortion

The class CA_AffineFraserDistortion is a data type with the F-values for describing the affine distortion of the Fraser-model. A full explanation is provided in C.3.

6.2.30 CA_SMACParameters

The class CA_SMACParameters is a data type with the parameters of the SMAC model. They consist of two P-values for describing the decentering distortion and an unlimited number of radial distortion coefficients K_i. A full explanation is provided in C.4.

6.2.31 CA_EbnerParameters

The class CA_EbnerParameters is a data type with the 12 Ebner-parameters (e_1 to e_{12}). A full explanation is provided in C.5.

6.2.32 CA_JacobsenParameters

The class CA_JacobsenParameters is a data type with the 15 Jacobsen parameters (j_1 to j_{15}, Tables C.1 and C.2). The distortion model of Jacobsen defines parameters from j_1 to j_{88} (Tables C.1 to C.9). However, only the first 15 are normative because the further have a product-specific meaning. A full explanation is provided in C.6.

6.3 Package OpticsSensor, Radiometry

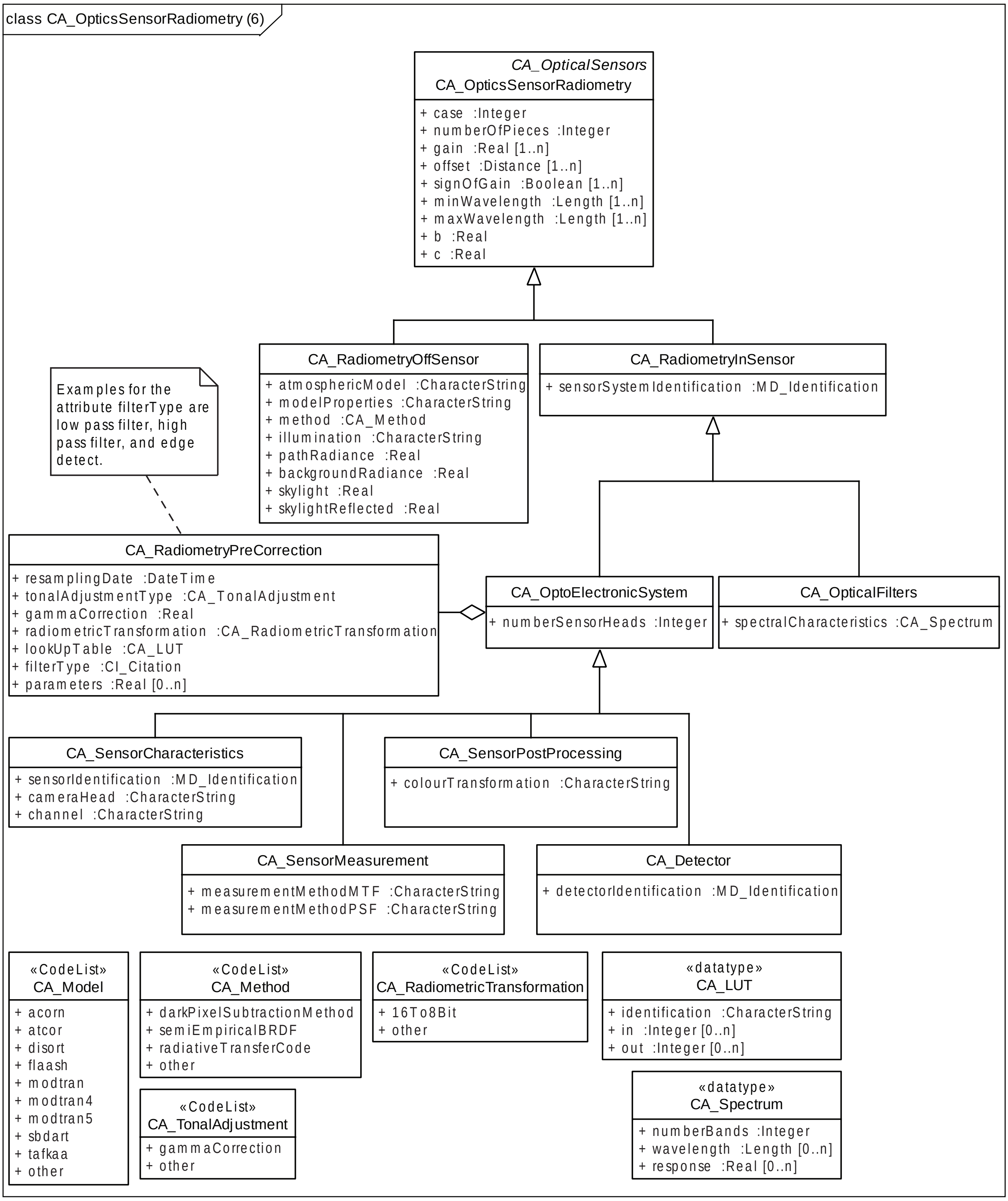
6.3.1 Semantics

The package OpticsSensor, part radiometry, contains the information of a radiometric calibration that is related to the data capturing process and splits into the two subparts termed off-sensor and in-sensor. The term off-sensor refers to atmospheric models and transfer methods of radiometry information. The term in-sensor refers to the opto-electronic system, to optical filters, and alike.

The conversion of Digital Number (DN) to object radiances is often done using a linear transformation (gain and offset). This approach covers the off-sensor and the in-sensor-influences in one and is thus defined in the superclass of the package (Figure 7).

This linear transformation is also applied to model the in-sensor influences only. Hence it transforms from Digital Number (DN) to at-sensor irradiances.

Figure 6 depicts the details of the class CA_OpticsSensorRadiometry and its subclasses apart from the sensor characteristics (6.3.14 – 6.3.24) and detectors(6.3.25 – 6.3.30).



NOTE The details of sensor characteristics and detector are excluded and are shown in Figures 8 and 9.

Figure 6 — Class diagram of the radiometry part of the package OpticsSensor

6.3.2 CA_OpticsSensorRadiometry

The class CA_OpticsSensorRadiometry is the superclass of CA_RadiometryOffSensor and CA_RadiometryInSensor, and is the most general class of the radiometry recording.

The attributes gain and offset define the transfer from Digital Numbers (DN) to at-sensor radiances. This part of ISO 19159 provides three cases for the linear transformation:

Case 1:

$$L_{sensor}(i,j) = k*DN(i,j) + d \tag{3}$$

Case 2:

$$L = (DN-1)*UCC \tag{4}$$

where

$L_{sensor}(i,j)$	is at-sensor radiance;
k	is the gain;
DN(i,j)	is the digital number;
d	is the offset;
UCC	are the unit conversion coefficients.

Case 99:

None of those formulae

The unit of radiances is watt per steradian per square metre.

A steradian is defined as the solid angle subtended at the centre of a sphere of radius *r* by a portion of the surface of the sphere whose area equals r^2.

The attribute case defines one of the above mentioned cases (1 or 2 or 99). The data type is Integer.

The attribute numberOfPieces defines the number of pieces in the case of a piecewise linear transformation. The data type is Integer.

The attributes gain and offset define the gain and the offset respectively. The multiplicity of *n* is provided for those sensors which do not have the same linear sensitivity across the complete spectral range.

The attribute signOfGain denotes the sign of the gain and has the data type Real with the values +1 and −1.

The attributes minWavelength and maxWavelength define the minimum and the maximum wavelengths for which the respective gain and offset is valid.

The attributes b and c are correction parameters for compensating the effect of path radiance and illumination factors such as sky light and reflected radiance.

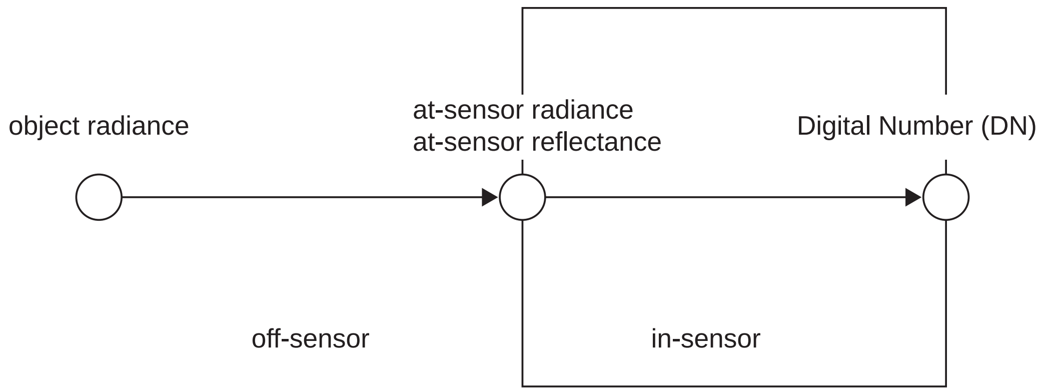


Figure 7 — Radiation path from an object to a Digital Number (DN)

6.3.3 CA_RadiometryOffSensor

The class CA_RadiometryOffSensor has all information regarding influences not generated by the sensor.

The attribute atmosphericModel defines the model that is applied for the atmospheric correction. The data type is CharacterString. Examples are given in 6.1.4.

The attribute modelProperties allows for a general description of the atmospheric model.

The attribute method defines the method applied for the atmospheric correction.

The attribute illumination defines the light conditions of the imaged object.

The attribute pathRadiance describes the amount of radiation that is added to the received total radiation by influences located along the track. The data type is Real.

The attribute backgroundRadiance describes the amount of radiation that is added to the received total radiation by influences from any background. The data type is Real.

The attribute skylight describes the amount of radiation received as scattered solar radiation from the atmosphere measured in a part of one hundred. The data type is Real.

The attribute skylightReflected describes the amount of radiation received as scattered solar radiation from the atmosphere and then reflected from adjacent objects such as buildings or the ground measured in a part of one hundred. The data type is Real.

6.3.4 CA_RadiometryInSensor

The class CA_RadiometryInSensor is the superclass of the classes CA_OptoElectronicSystem and CA_OpticalFilters.

The attribute SensorSystemIdentification allows for identifying the sensor system.

6.3.5 CA_OptoElectronicSystem

The class CA_OptoElectronicSystem has all information necessary for the radiometric calibration of such a system. An opto-electronic system consists of one or more sensors such as a camera head.

The attribute numberSensorHeads defines the number of sensors that make up the system. The data type is Integer.

6.3.6 CA_SensorMeasurement

The class CA_SensorMeasurement has all information about the measurement methods applied for determining any of the calibrated parameters.

The attribute measurementMethodMTF defines the measurement method for the determination of the MTF.

The attribute measurementMethodPSF defines the measurement method for the determination of the PSF.

6.3.7 CA_SensorPostProcessing

The class CA_SensorPostProcessing has all information about image modifications during post processing.

The attribute colourTransformation defines the coefficients that are used to perform a colour transformation.

6.3.8 CA_RadiometryPreCorrection

The class CA_RadiometryPreCorrection has all information about the radiometric modification of the image data during the processing from the status raw-data to the status first original.

The attribute resamplingDate defines the time of processing.

The attribute tonalAdjustmentType defines the type of tonal adjustment.

The attribute gammaCorrection defines the amount of the gamma correction.

The attribute radiometricTransformation defines the change of the grey value depth.

The attribute lookUpTable defines a look-up-table for a radiometric change of the image.

The attribute filterType has the data type CI_Citation and describes the filter applied for the radiometric change. Examples of the filter type are low pass filter, high pass filter, and edge detect. Normally the citation will contain a reference to the scientific literature describing the filter.

The attribute parameters [0..n] defines other involved parameters.

6.3.9 CA_OpticalFilters

The class CA_OpticalFilters has all information about the optical filters involved.

The attribute spectralCharacteristics defines the transmission-curve of the filter.

6.3.10 CA_Method

The class CA_Method is a code list that has the codes darkPixelSubtractionMethod, semiEmpiricalBRDF, radiativeTransferCode, and other.

6.3.11 CA_TonalAdjustment

The class CA_TonalAdjustment is a code list with the codes gammaCorrection and other.

6.3.12 CA_RadiometricTransformation

The class CA_RadiometricTransformation is a code list with the codes 16To8Bit and other.

6.3.13 CA_LUT

The class CA_LUT is a data type that defines a look-up-table, which is defined by the attributes identification, in [0..n], and out [0..n]. The value-pairs in-out define the transfer-curve.

6.3.14 CA_SensorCharacteristics

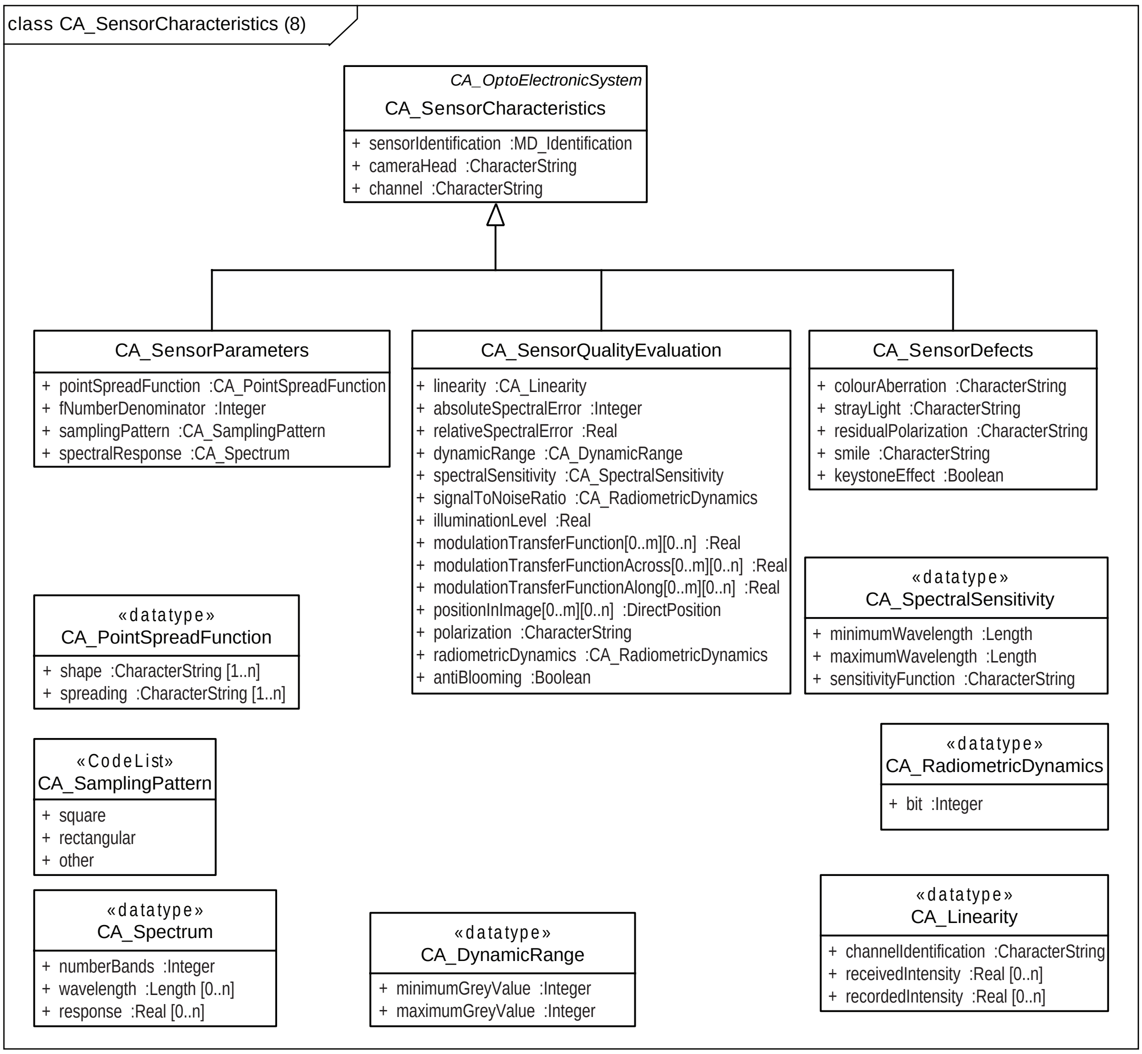


Figure 8 — Class diagram of CA_SensorCharacteristics

The class CA_SensorCharacteristics has all identification information about the sensor.

The attribute sensorIdentification lets the sensor be identified.

The attribute cameraHead defines the camera or sensor head for which the information is valid.

The attribute channel defines the channel for which the information is valid.

6.3.15 CA_SensorParameters

The class CA_SensorParameters has all information that characterizes the imaging performance of the sensor.

The attribute pointSpreadFunction defines the point spread function (PSF) of the sensor. The data type is CA_PointSpreadFunction.

The attribute fNumberDenominator defines the denominator of the aperture of the sensor.

The attribute samplingPattern defines the spatial distribution of the sampled points. The data type is CA_SamplingPattern.

The attribute spectralResponse defines the spectral response characteristics of the sensor. The data type CA_Spectrum is defined in package OpticsCalibrationFacility, part Radiometry.

6.3.16 CA_SensorQualityEvaluation

The class CA_SensorQualityEvaluation has all information about the radiometric quality of the sensor.

The attribute linearity defines the spectral response-curve of the sensor.

The attribute absoluteSpectralError defines the difference between two radiometric measurements under the same off-sensor conditions, reported with the unit grey values [Integer].

The attribute relativeSpectralError defines the difference between two radiometric measurements under the same off-sensor conditions, reported as a ratio of the difference [grey values] and the total grey value number [grey values].

The attribute dynamicRange defines the range of distinguishable grey values of the sensor. The dynamic range has the data type integer and is computed from the distinguishable digital numbers (DN) as follows:

$$n\left[dB\right] = 20 \log DN \tag{5}$$

or

$$DN = 10^{\frac{n\left[dB\right]}{20}} \tag{6}$$

where

n is the dynamic range;

DN are the effective digital numbers.

The attribute spectralSensitivity defines the spectral sensitivity of the sensor.

The attribute signalToNoiseRatio characterizes the noise of the sensor.

The attribute illuminationLevel defines the illumination level for which the attribute signalToNoiseRatio is valid. The unit of illuminationLevel is watts per square metre.

The following four attributes define the Modulation Transfer Function (MTF). It is defined as a matrix with m rows and n columns.

The attribute modulationTransferFunction defines the Modulation Transfer Function (MTF) of the sensor.

The attribute modulationTransferFunctionAcross defines the Modulation Transfer Function (MTF) of the sensor across the flight-track.

The attribute modulationTransferFunctionAlong defines the Modulation Transfer Function (MTF) of the sensor along the flight-track.

The attribute positionInImage specifies the positions in the image to which the MTF-values are related.

The attribute polarization defines the polarization characteristics of the sensor.

The attribute radiometricDynamics defines the number of distinguishable grey values.

The attribute antiBlooming specifies whether a sensor is equipped with anti-blooming techniques or not.

6.3.17 CA_SensorDefects

The class CA_SensorDefects has all information about defects of the sensor.

The attribute colourAberration defines a geometric bias of the co-registration of the colour channels. The data type is CharacterString.

The attribute strayLight defines the amount of stray light of the sensor. The data type is CharacterString.

The attribute residualPolarization defines the non-compensated parts of the polarization. The data type is CharacterString.

The attribute smile describes the smile distortion of the optical system. The data type is CharacterString.

The attribute keystoneEffect describes the presence of the keystone effect. This effect is caused by the perspective transformation that is applied while the imaging of an object with an optical sensor that is based on the central perspective. The data type of the attribute keystone is Boolean.

6.3.18 CA_Linearity

The class CA_Linearity is a data type that defines the linearity of the sensor response. The value-pairs receivedIntensity – recordedIntensity define the response-curve of the sensor.

The attribute channelIdentification defines the identification for the channel.

The attribute receivedIntensity[0..n] defines the radiometric activation of the sensor.

The attribute recordedIntensity[0..n] defines the recorded intensity of the sensor.

6.3.19 CA_RadiometricDynamics

The class CA_RadiometricDynamics is a data type that defines a bit-value.

6.3.20 CA_SpectralSensitivity

The class CA_SpectralSensitivity is a data type that defines the spectral range based on wavelengths.

The attribute minimumWavelength defines the minimum wavelength.

The attribute maximumWavelength defines the maximum wavelength.

The attribute sensitivityFunction defines the function that relates the received radiation to the sensor's response.

6.3.21 CA_PointSpreadFunction

The class CA_PointSpreadFunction is a data type which contains characteristic parameters of the point spread function, shape and spreading. Both can be described with characteristic parameters or as a discrete function in spatial or Fourier space coordinates.

Both attributes have the data type CharacterString.

6.3.22 CA_SamplingPattern

The class CA_SamplingPattern is a code list and has the values square, rectangular, and other.

6.3.23 CA_Spectrum

The class CA_Spectrum is a data type that defines a spectrum.

The attribute numberBands defines the quantity of spectral bands and has the data type Integer.

The attribute wavelength [0..n] defines the central wavelength of the respective band and has the data type Length.

The attribute response [0..n] defines the intensity of the response in a band and has the data type Real.

6.3.24 CA_DynamicRange

The class CA_DynamicRange is a data type that defines the range regarding a radiometric property. It has the two values minimumGreyValue and maximumGreyValue which denote the lower border of the range and the upper border of the range respectively.

The attribute maximumGreyValue is related to the saturation of the detector.

6.3.25 CA_Detector

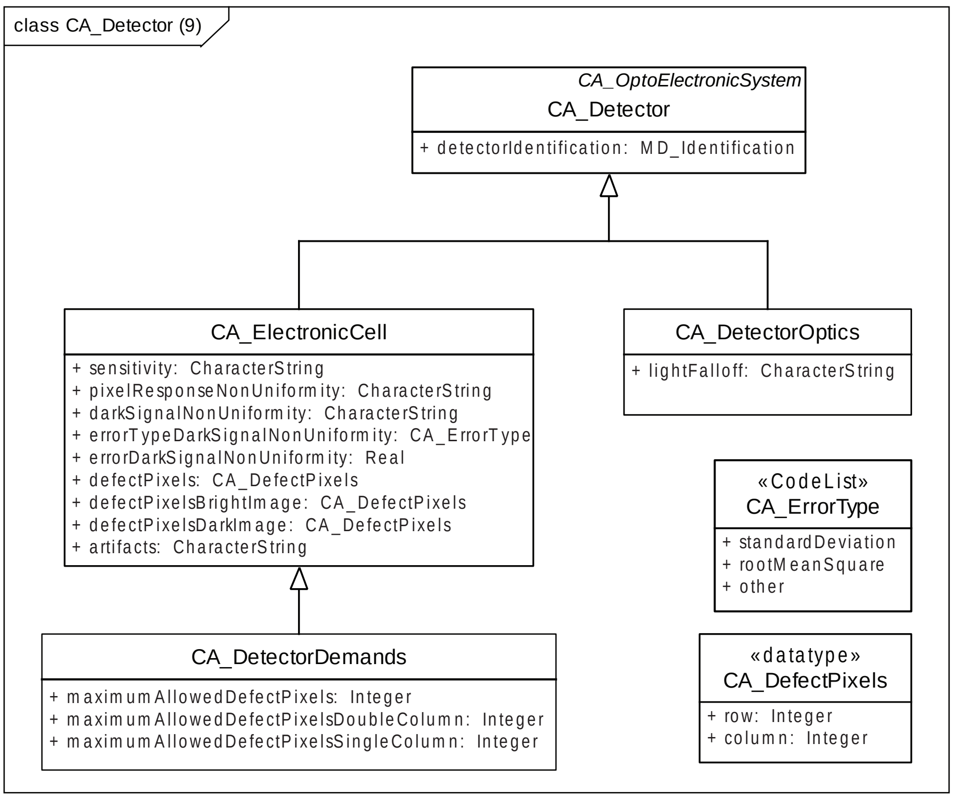


Figure 9 — Class diagram of CA_Detector

The class CA_Detector has all information necessary to identify a detector.

The attribute detectorIdentification lets the detector be identified and has the data type MD_Identification.

6.3.26 CA_ElectronicCell

The class CA_ElectronicCell has all information necessary for the radiometric calibration regarding a detector element or a detector array.

The attribute sensitivity defines the response of an individual detector element relative to the activation. The data type is CharacterString.

The attribute pixelResponseNonUniformity (PRNU) defines inhomogenities of the response of the detectors of a detector array to activation. The data type is CharacterString.

The attribute darkSignalNonUniformity (DSNU) defines the response of a detector element if no visible or infrared light is present. This activation is mostly caused by imperfection of the detector. The data type is CharacterString.

The attribute errorTypeDarkSignalNonUniformity (DSNU) defines the type of error of the darkSignalNonUniformity and has the data type CA_ErrorType.

The attribute errorDarkSignalNonUniformity (DSNU) defines the relative error of the attribute darkSignalNonUniformity and has the data type Real.

The attribute defectPixels defines the image-position of a defect pixel and has the data type CA_DefectPixels.

The attribute defectPixelsBrightImage defines the image-position of a defect pixel that is defect if the activation is intense (bright image). The data type is CA_DefectPixels.

The attribute defectPixelsDarkImage defines the image-position of a defect pixel that is defect if the activation is low (dark image). The data type is CA_DefectPixels.

The attribute artifact describes other deficiencies of the detector. The data type is CharacterString.

6.3.27 CA_DetectorOptics

The class CA_DetectorOptics has all information necessary to describe the optics of a detector.

The attribute lightFalloff defines the decrease of activation of detector elements toward the border/end of the detector array due to the imperfection of the lens. This is also called vignetting. The measurement is done in the laboratory using a uniform light source to create a sensitivity profile. The data type is CharacterString.

6.3.28 CA_DetectorDemands

The class CA_DetectorDemands contains threshold values for the quality parameters found in the calibration process. Those threshold values are defined as a quality measure of the calibration process.

The attribute maximumAllowedDefectPixels defines the maximum allowed number of defect pixels on the entire sensor. The data type is Integer.

The attribute maximumAllowedDefectPixelsDoubleColumn defines the maximum allowed number of defect pixels on a pair of columns. The data type is Integer.

The attribute maximumAllowedDefectPixelsSingleColumn defines the maximum allowed number of defect pixels on a single column. The data type is Integer.

6.3.29 CA_DefectPixels

The class CA_DefectPixels is a data type that defines the row and the column of a defect (incorrectly responding) pixel. The data type is Integer in both cases.

6.3.30 CA_ErrorType

The class CA_ErrorType is a code list with the codes standardDeviation, rootMeanSquare, and other.

The standard deviation is defined as given by Formula (7):

$$\sigma_M = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N} (Z_i - z_m)^2} \tag{7}$$

where

σ_M is the standard deviation of measured differences;

N is the number of observations;

Z_i is the ith observable Z;

z_t is the mean value of the observable Z (arithmetic mean, $z_m = \frac{1}{N}\sum_{i=1}^{N} Z_i$).

The root mean square error (RMSE) is defined as given by Formula (8):

$$\sigma_z = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Z_i - z_t)^2} \tag{8}$$

where

σ_z is the root mean square error (RMSE);

N is the number of observations;

Z_i is the ith observable Z;

z_t is the true value of the observable Z.

6.4 Package OpticsCalibrationFacility, Geometry

6.4.1 Semantics

The package OpticsCalibrationFacility is designed to contain information that is related to a calibration laboratory and to an in-flight calibration. Calibration instruments and test fields may be applied in a laboratory calibration while only test fields are common during in-flight calibrations. The package provides detailed information about the test field targets, the calibration photo flight, and the bundle-adjustment-based determination of the calibration results, termed self-calibration.

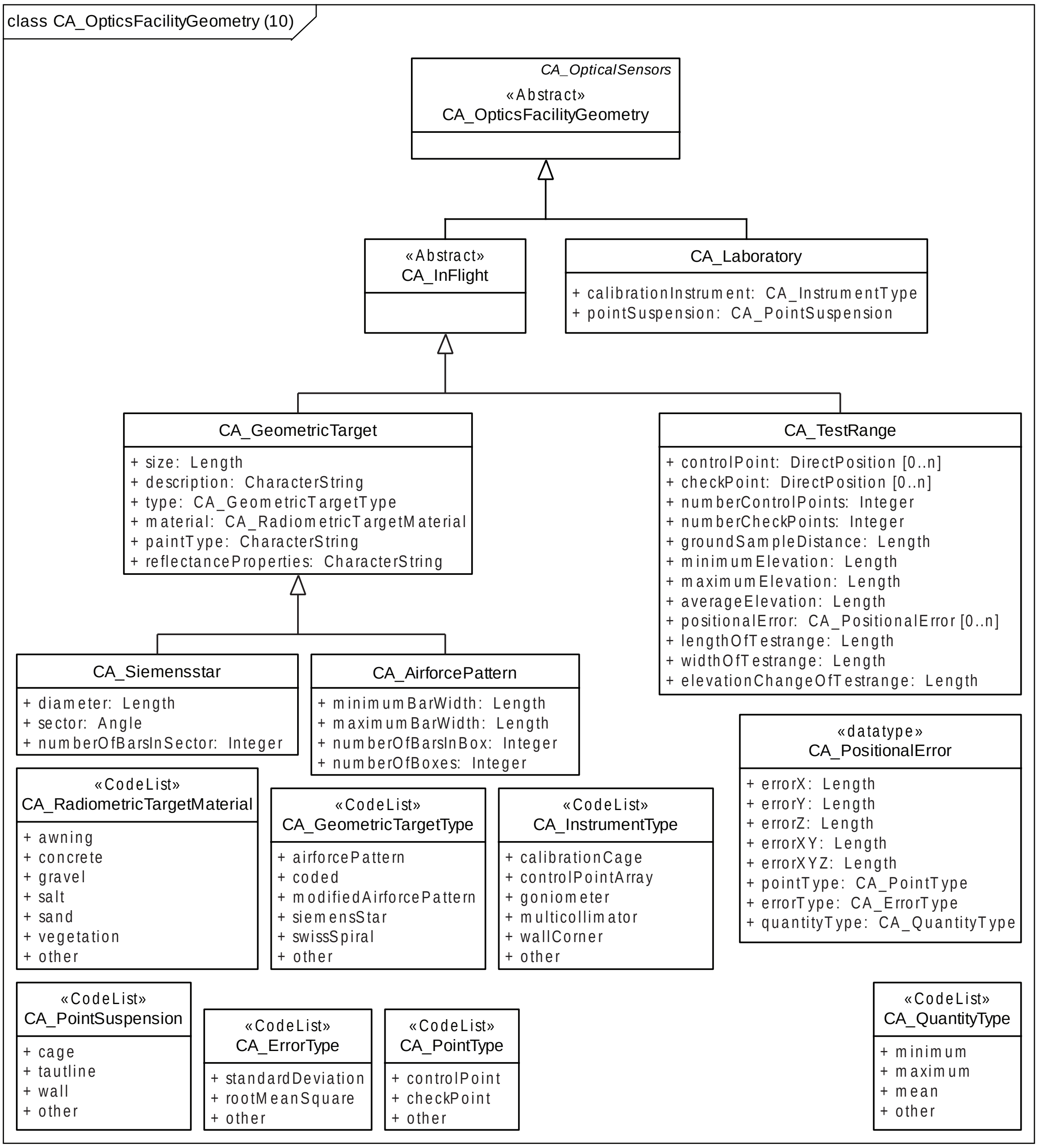


Figure 10 — Class diagram of the geometry part of the package OpticsCalibrationFacility

6.4.2 CA_OpticsFacilityGeometry

The class CA_OpticsFacilityGeometry is an abstract class that is the superclass of all related classes for geometry calibration facilities.

6.4.3 CA_InFlight

The class CA_InFlight is the superclass of the classes CA_GeometricTarget and CA_TestRange, and has the stereotype abstract because it has no attributes.

6.4.4 CA_GeometricTarget

The class CA_GeometricTarget has all information about the targets.

The attribute size defines the width of the two-dimensional bounding box around the target. The data type is Length.

The attribute description allows for a free text description of the target. An example is “Painted Target” or “White squares 0.5m on each side”. The data type is CharacterString.

The attribute type defines the characteristic of the target according to the code list set in the class CA_GeometricTargetType.

The attribute material defines the substance of the target’s surface such as paint or awning. The data type of this attribute is CA_RadiometricTargetMaterial that is defined in the package RadiometryCalibrationFacility.

The attribute paintType describes the characteristics of the paint. The data type is CharacterString.

The attribute reflectanceProperties describes the peculiarity of the reflectance. The data type is CharacterString.

6.4.5 CA_Siemensstar

The class CA_Siemensstar has all information about a target of type Siemens star.

The attribute diameter defines the diameter of the Siemens star. The data type is Length.

The attribute sector defines the angular width of the Siemens star. For example: if the attribute value is 180°, then the Siemens star is drawn as a semicircle. The data type is Angle.

The attribute numberOfBarsInSector defines the partitioning of the sector. The attribute defines a bar-pair. A bar-pair is a white sector and a black sector.

EXAMPLE If the attribute sector is set to 180° and the attribute numberOfBarsInSector has a value of 10, then the Siemens star has 10 white and 10 black sections with an angular width of 9° each. The data type is Integer.

Figure 11 — Siemensstar on a roof

6.4.6 CA_AirforcePattern

The class CA_AirforcePattern has all information about the target of type airforce pattern.

The attributes minimumBarWidth and maximumBarWidth define the minimum and maximum width of the target-bars. The data type is Length.

The sections of the airforce pattern are called boxes. The attribute numberOfBarsInBox define the quantity of bars in one box. The attribute numberOfBoxes defines the quantity of all boxes. The data type is Integer.

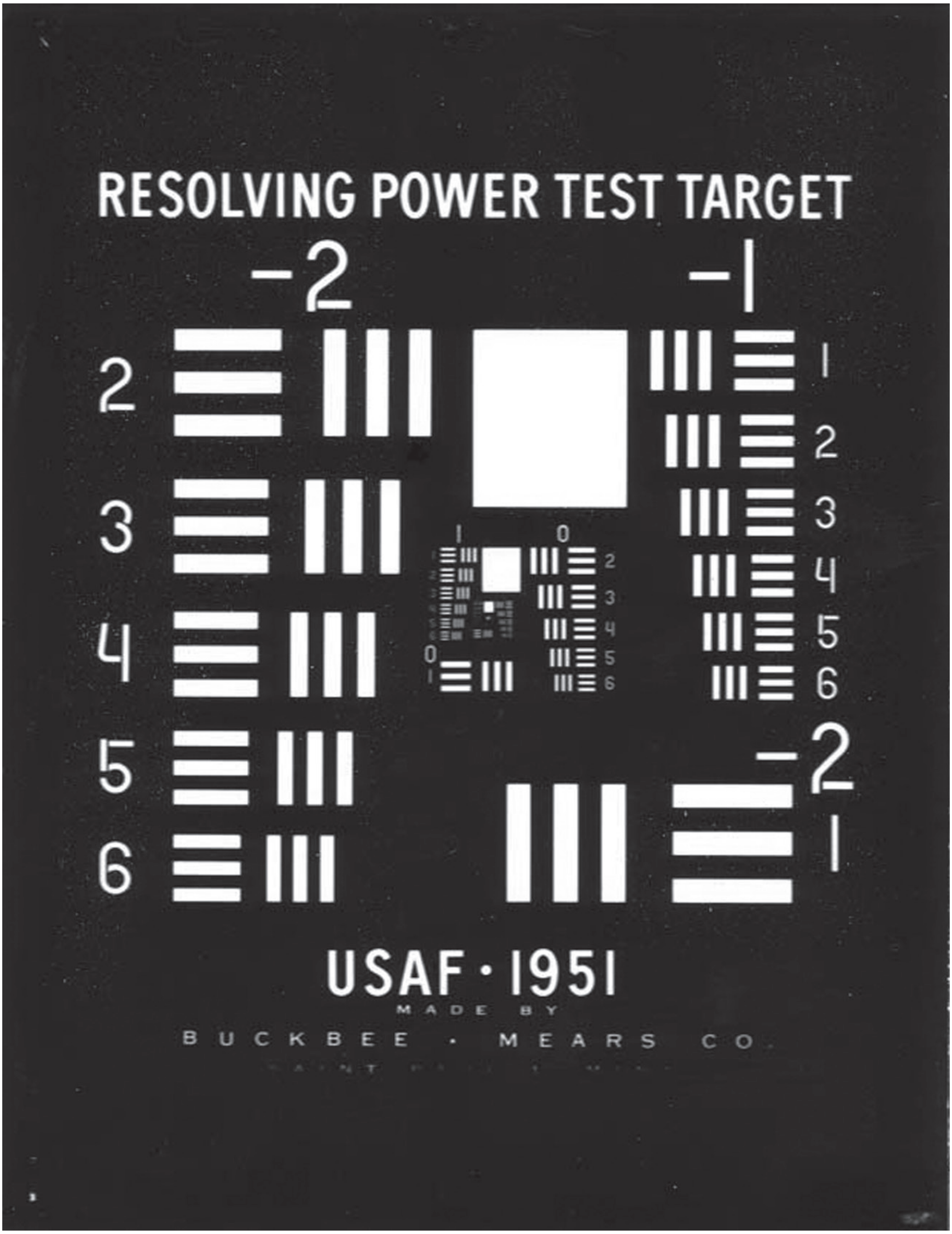


Figure 12 — Resolution test pattern conforming to MIL-STD-150A standard set by US Air Force in 1951

6.4.7 CA_TestRange

The class CA_TestRange has all information that is valid for the entire test range.

The attributes controlPoint [0..n] and checkPoint [0..n] define the control points and the check points respectively. Their data type is DirectPosition.

The attributes numberControlPoints and numberCheckPoints define their quantity in the test field. Their data type is Integer.

The attribute groundSampleDistance defines the smallest Ground Sample Distance (GSD) that can sensibly be applied for a sensor calibration on this test range. The targets have a given size. Therefore they may not be small enough to be used for a calibration process with a smaller GSD than stated in the attribute groundSampleDistance. The data type is Length.

The attributes minimumElevation, maximumElevation, and averageElevation define the elevation range of the test field and its average elevation. The average elevation should be computed as the arithmetic mean of all targets. The data type is Length.

The attribute positionalError characterizes the geometric accuracy of the test range. The data type is CA_PositionalError.

The attributes lengthOfTestrange, widthOfTestrange, and elevationChangeOfTestrange describe the three-dimensional extent of the test range. The data type is Length.

6.4.8 CA_Laboratory

The class CA_Laboratory has information related to the instruments utilized during the calibration.

The attribute calibrationInstrument can be coded according to the code list CA_InstrumentType.

The attribute pointSuspension defines the method of attaching control points and check points to a reference base. This attribute allows for the distinction between a target attached to a cage, a wall, and a target attached to a tautline which are is mostly stretched between the floor and the ceiling, and other. The data type is CA_PointSuspension.

6.4.9 CA_PositionalError

The class CA_PositionalError is a data type that specified the positional error of a point.

One group of attributes define the dimension of the error, i.e. errorX, errorY, and errorZ for 1-dimensional cases, error XY for the two-dimensional case, and errorXYZ for the 3-dimensional case. The data type is Length in all cases.

Three other attributes are named pointType to distinguish between control points and check points, errorType to distinguish between standard deviation and root mean square error, quantityType to inform what the error represents (minimum, maximum, and mean).

NOTE The different quality measures are defined in ISO 19157.

6.4.10 CA_PointType

The class CA_PointType is a code list with the codes controlPoint, checkPoint, and other.

6.4.11 CA_QuantityType

The class CA_QuantityType is a code list with the codes minimum, maximum, mean and other.

The quantity type is an attribute which defines whether the positional error is the maximum, a mean, or the minimum of a set of errors.

6.4.12 CA_PointSuspension

The class CA_PointSuspension is a code list with the codes cage, tautline, wall, and other.

6.4.13 CA_InstrumentType

The class CA_InstrumentType is a code list with the entries calibrationCage, controlPointArray, goniometer, multicollimator, wallCorner, and other.

6.4.14 CA_GeometricTargetType

The class CA_GeometricTargetType is a code list with the entries airforcePattern, coded, modifiedAirforcePattern, siemensStar, swissSpiral, and other.

6.5 Package OpticsCalibrationFacility, Radiometry

6.5.1 Semantics

The part radiometry of the package OpticsCalibrationFacility contains all information that is related to the calibration equipment including the laboratory and the in-flight environment.

This part of the package addresses standardized test fields and targets, properties of the sensor system, and environmental conditions.

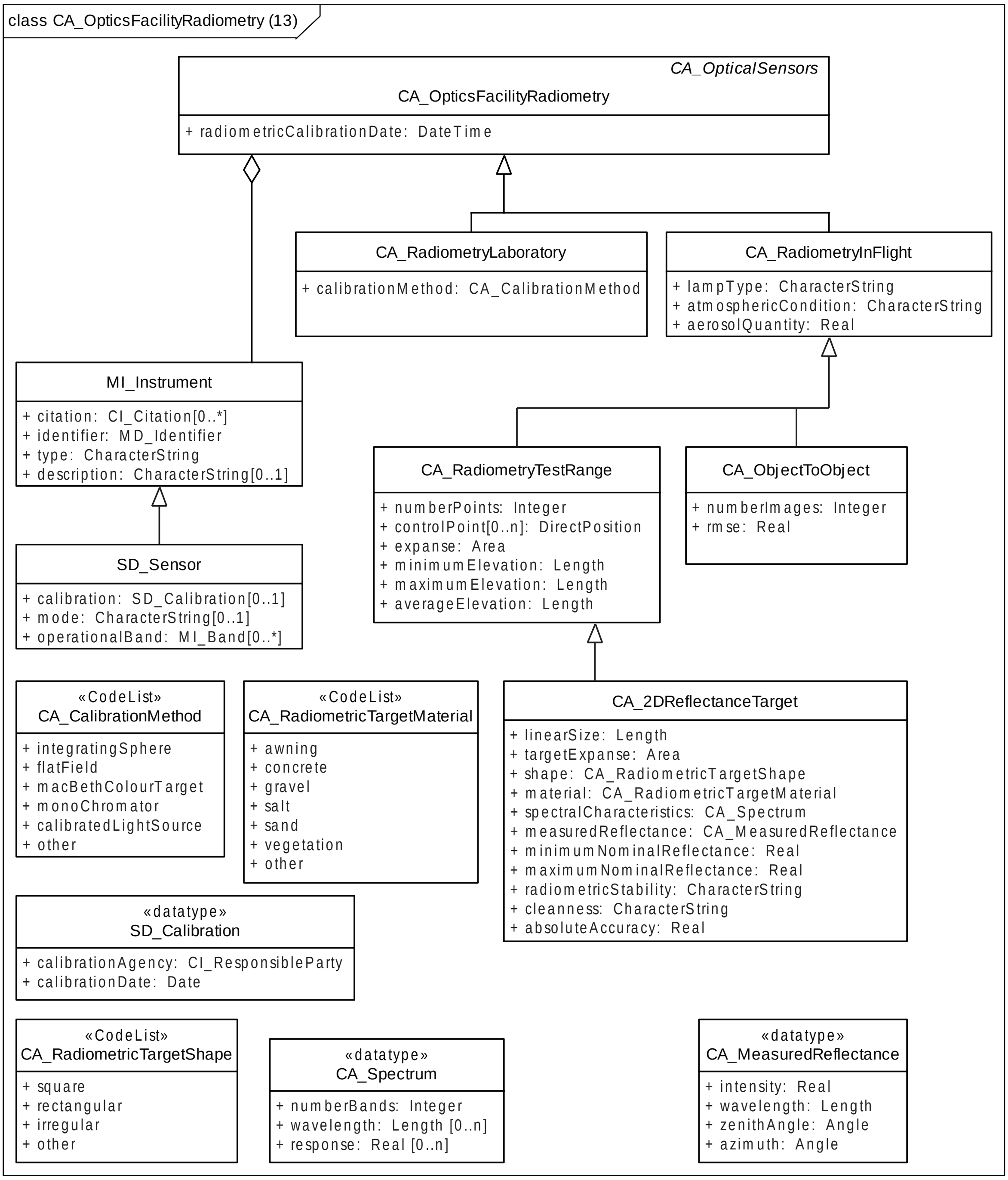


Figure 13 — Class diagram of the radiometry part of the package OpticsCalibrationFacility

6.5.2 CA_OpticsFacilityRadiometry

The class CA_OpticsFacilityRadiometry defines all information that is valid for the entire radiometric calibration.

The attribute radiometricCalibrationDate defines the date and time when the calibration was performed and has the data type DateTime.

6.5.3 CA_RadiometryLaboratory

The class CA_Laboratory has all information regarding the radiometric calibration in a laboratory.

The attribute calibrationMethod defines the method applied for the calibration. The data type is CA_CalibrationMethod.

6.5.4 CA_RadiometryInFlight

The class CA_RadiometryInFlight is the superclass of the classes CA_RadiometryTestRange and CA_ObjectToObject.

The attribute lampType defines the type of illumination used and has the data type CharacterString.

The attribute atmosphericCondition is described with a data type Character String.

NOTE Two types of the atmospheric condition are tropical and midlatitude summer.

The attribute aerosolQuantity denotes the visibility of the atmosphere as a part of one hundred. The data type is Real.

Further parameters regarding the properties of test range are defined in the class CA_TestRange in the package GeometricCalibrationFacility.

6.5.5 CA_RadiometryTestRange

The class CA_RadiometryTestRange is the superclass of the class CA_2DReflectanceTarget and has all information about the test ranges used in the radiometric calibration.

The attribute numberPoints defines the number of targets in the test range and has the data type Integer.

The attribute controlPoint [0..n] defines the position of the control points and has the data type DirectPosition.

The attribute expanse defines the two-dimensional size of the test field and has the data type Area.

The attributes minimumElevation, maximumElevation, and averageElevation define the lowest, the highest, and the average elevation of the test field respectively. The data type is Length in all cases.

6.5.6 CA_2DReflectanceTarget

The class CA_2DReflectanceTarget has all information about the two-dimensional reflectance targets. Those targets may be small with a size of a few square metres as well as large like the large homogenous test fields prepared for satellite applications. In the latter case the area of the two-dimensional reflectance target is identical with the area of the test field.

The attribute linearSize defines the width of a square-shaped or round target and has the data type Length.

The attribute targetExpanse defines the two-dimensional size of the target and has the data type Area.

The attribute shape defines the shape of the target and has the data type CA_RadiometricTargetShape.

The attribute material defines the surface material of the target and has the data type CA_RadiometricTargetMaterial.

The attribute spectralCharacteristics defines the spectral characteristics of the target under defined illumination conditions and has the data type CA_Spectrum.

The attribute measuredReflectance defines the reflectance of the target and has the data type CA_MeasuredReflectance.

The attributes minimumNominalReflectance and maximumNominalReflectance define the range of reflectances of the target and has the data type Real.

The attribute radiometricStability defines the radiometric stability of the target and has the data type CharacterString.

The attribute cleanness defines the cleanness of the target and has the data type CharacterString.

The attribute absoluteAccuracy defines an estimate of the accuracy of the reference value and has the data type Real.

6.5.7 CA_ObjectToObject

The class CA_ObjectToObject has all information for a radiometric calibration based of an object-to-object comparison. With this approach the quality of radiometric corrections is evaluated by comparing the image of an object in two or more photos.

The attribute numberImages defines the number of photos in which the object was photographed and analysed, and has the data type Integer.

The attribute rmse defines the root mean square error of the analysis normalized to the full dynamic range of the digital image (see 6.3.30). The data type is Real.

6.5.8 MI_Instrument

The class MI_Instrument is defined in ISO 19115-2 and contains instrument-specific parameters.

The attribute citation [0..*] sets a complete citation of the instrument.

The attribute identifier defines a unique identification of the instrument.

The attribute type is a name of the type of instrument.

EXAMPLES framing, line-scan, push-broom, pan-frame, whiskbroom

The attribute description [0..1] sets a textual description of the instrument.

6.5.9 SD_Sensor

The class SD_Sensor is defined in ISO/TS 19130 and contains the characteristics of the sensor.

The attribute calibration contains information about determination of the relation between instrument readings and physical parameters. The data type is SD_Calibration.

The attribute mode defines the type of observation being made by the sensor and has the data type CharacterString.

The attribute operationalBand defines the wavelengths of the electromagnetic spectrum being observed by the sensor and has the data type MI_Band.

6.5.10 CA_CalibrationMethod

The class CA_CalibrationMethod is a code list with the codes integratingSphere, flatField, macBethColourTarget, monoChromator, calibratedLightSource, and other. Those codes are used for characterizing a laboratory calibration.

6.5.11 CA_RadiometricTargetShape

The class CA_RadiometricTargetShape is a code list with the codes square, rectangular, irregular, and other.

6.5.12 CA_RadiometricTargetMaterial

The class CA_RadiometricTargetMaterial is a code list with the codes awning, concrete, gravel, salt, sand, vegetation, and other.

6.5.13 CA_MeasuredReflectance

The class CA_MeasuredReflectance is a data type that defines the measured reflectance of a target with respect to a reference.

The attributes intensity and wavelength define the measured values and has the data type Length.

The attribute zenithAngle defines the angle from the zenith towards the measuring instrument and has the data type Angle.

The attribute azimuth defines the horizontal angle to the measuring instrument counted counterclockwise from North and has the data type Angle.

NOTE A reflectance measurement requires also the knowledge of the attributes solarZenithAngle and solarAzimuth. Those two are defined in the class CA_Radiation.

6.5.14 SD_Calibration

The class SD_Calibration is a data type defined in ISO/TS 19130 and contains the circumstances of determination of relation between instrument readings and physical parameters. The parameters defined here regard the most recent calibration.

The attribute calibrationAgency defines the authority under which calibration took place and has the data type CI_ResponsibleParty.

The attribute calibrationDate defines the date when the calibration was carried out and has the data type Date.

6.6 Package OpticsValidation

6.6.1 General

The class CA_OpticsValidation is an abstract class that is the superclass of CA_GeometryValidation and CA_RadiometryValidation (see Figure 14). The class OpticsValidation contains all information related to the validation of the geometric and radiometric calibration of a remote sensing imagery sensor system.

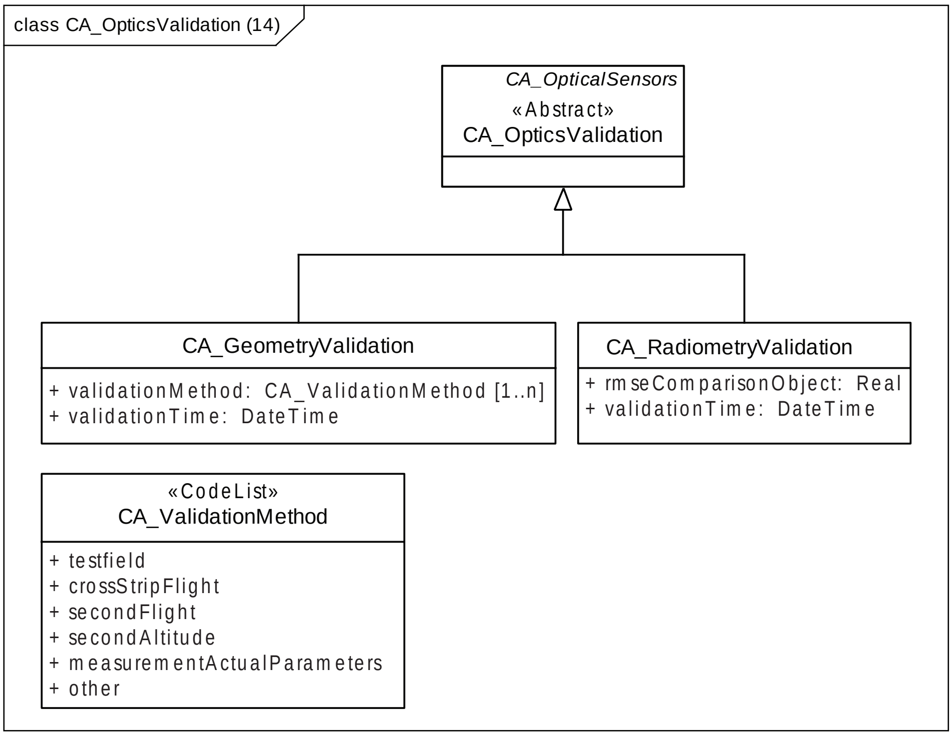


Figure 14 — Class diagram of the package OpticsValidation

6.6.2 CA_GeometryValidation

The class CA_GeometryValidation has all information necessary to perform a validation of the geometric calibration.

The attribute validationMethod has information about the validation method and has the data type CA_ValidationMethod.

The attribute validationTime defines the time of the validation and has the data type DateTime.

6.6.3 CA_ValidationMethod

The class CA_ValidationMethod is a code list with the codes testfield, crossStripFlight, secondFlight, secondAltitude, measurementActualParameters, and other.

6.6.4 CA_RadiometryValidation

The class CA_RadiometryValidation has all information necessary to perform a validation of the radiometric calibration.

The attribute rmseComparisonObject defines the result of the validation and has the data type Real.

The attribute validationTime defines the time of the validation and has the data type DateTime.

7 Documentation

7.1 Semantics

The term documentation may refer to any form of documentation of the results.

7.2 Package Documentation

7.2.1 Semantics

The package Documentation contains the parameters that are useful for the documentation of the calibration results. The most important definitions are those regarding processing levels and quality classes (see Figure 15).

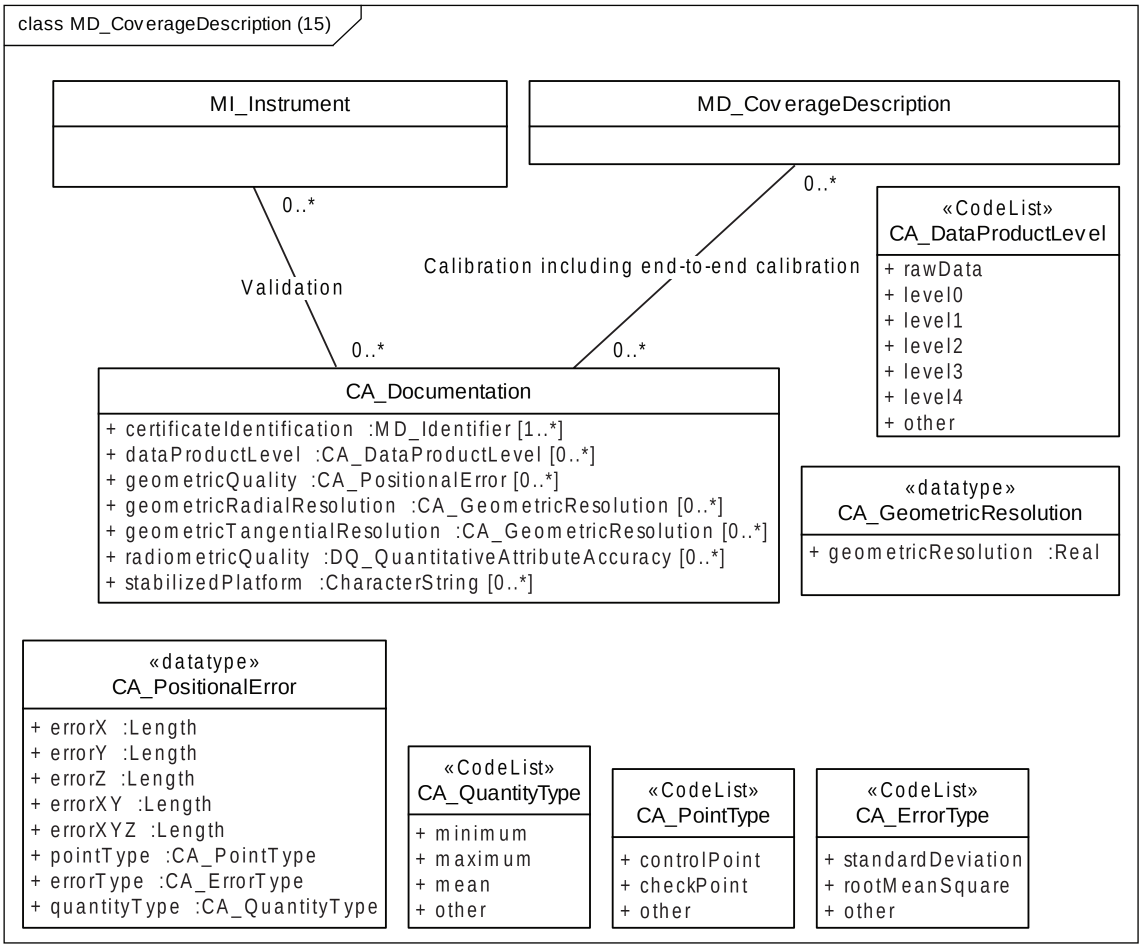


Figure 15 — Class diagram of the package documentation

7.2.2 CA_Documentation

The class CA_Documentation has all other information that may be documented.

The attribute certificateIdentification gives information for the identification of the certificate and has the data type MD_Identification.

The attribute dataProductLevel gives information about the processing steps that have been applied to a data set. The data type is CA_DataProductLevel.

The attribute geometricQuality gives information about the geometric quality. The attribute has the data type CA_PositionalError.

NOTE The different quality measures are defined in Annex D and in ISO 19157.

The attribute geometricRadialResolution defines the resolution of imagery along a radius from the image centre. The data type CA_GeometricResolution is defined in the package InteriorOrientation.

The attribute geometricTangentialResolution defines the resolution of imagery in the tangential direction regarding the image centre. The data type CA_GeometricResolution is defined in the package InteriorOrientation.

The attribute radiometricQuality characterizes the radiometric quality, and the data type is DQ_QuantitativeAttributeAccuracy.

The attribute stabilizedPlatform gives information about the applied stabilized platform, and the data type is CharacterString.

7.2.3 CA_DataProductLevel

The class CA_DataProductLevel is a code list with the codes listed and explained in Table 2.

The data product levels defined in this class are individually defined by the data providers and vary considerably. The lowest level refers to the raw data or alike while higher levels are related to various stages of processing.

Table 2 — Data product levels (example)

raw data	Unprocessed original data.
level0	Reconstructed unprocessed data at full space-time resolution with all available supplemental information to be used in subsequent processing (e.g. ephemeris, health and safety) appended.
level1	Reconstructed unprocessed data at full resolution, timereferenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and geo-referencing parameters (e.g. ephemeris) computed and appended but not applied to the L0 data. Radiometrically corrected and calibrated data in physical units at full instrument resolution as acquired.
level2	Derived geophysical parameters (e.g. sea surface temperature and surface reflectance) at the same resolution and location as L1 source data.
level3	Data or retrieved geophysical parameters (e.g. leaf area index) which have been spatially and/or temporally re-sampled (i.e. derived from L1 or L2 products), usually with some completeness and consistency. Such re-sampling may include averaging and compositing.
level4	Model output or results from analysis of lower level data (i.e. parameters that are not directly measured by the instruments, but are derived from these measurements).
other	

Annex A
(normative)

Abstract test suite

A.1 Semantics

Conformance to this part of ISO 19159 consists of either service conformance or data conformance.

The Abstract test suite has six conformance classes.

a) Project;

b) OpticsSensor: Geometry;

c) OpticsSensor: Radiometry;

d) OpticsCalibrationFacility: Geometry;

e) OpticsCalibrationFacility: Radiometry;

f) OpticsValidation;

g) Documentation.

A.2 Project

A.2.1 Service conformance

a) Test purpose: to verify the use of the appropriate interface for a project.

b) Test method: inspect the documentation of the service interface to verify the use of interfaces defined in the references in c).

c) References: 6.1.2 to 6.1.6.

A.2.2 Data conformance

a) Test purpose: to verify an adequate application class for the expression of a project service.

b) Test method: inspect the documentation of the application schema or profile and exhibit the required correspondence.

c) References: 6.1, including the following data types:

   1) CA_CalibrationType, 6.1.7;

   2) CA_TargetEnvironment, 6.1.8;

   3) CA_IrradianceModel, 6.1.9.

A.3 Sensor Geometry

A.3.1 Service conformance

a) Test purpose: to verify the use of the appropriate interface for a sensor geometry service.

b) Test method: inspect the documentation of the service interface to verify the use of interfaces defined in the references in c).

c) References: 6.2.1 to 6.2.13 and 6.2.19 to 6.2.23.

A.3.2 Data conformance

a) Test Purpose: to verify an adequate application class for the expression of an interior orientation.

b) Test Method: inspect the documentation of the application schema or profile and exhibit the required correspondence.

c) References: 6.2, including the following data types and code lists:

1) CA_TemperatureRange, 6.2.14;

2) CA_Temperature, 6.2.15;

3) CA_GeometricResolution, 6.2.16;

4) SD_ShapeCode, 6.2.17;

5) SD_ArrayDimension, 6.2.18;

6) CA_SelfCalibrationModel, 6.2.24;

7) CA_RadialDistortion, 6.2.25;

8) CA_DecenteringDistortion, 6.2.26;

9) CA_AffineDistortion, 6.2.27;

10) CA_TangentialDistortion, 6.2.28;

11) CA_AffineFraserDistortion, 6.2.29;

12) CA_SMACParameters, 6.2.30;

13) CA_EbnerParameters, 6.2.31;

14) CA_JacobsenParameters, 6.2.32;

A.4 Sensor Radiometry

A.4.1 Service conformance

a) Test purpose: to verify the use of the appropriate interface for an optics sensor, radiometry service.

b) Test method: inspect the documentation of the service interface to verify the use of interfaces defined in the references in c).

c) References: 6.3.1 to 6.3.9 and 6.3.19 to 6.3.26.

A.4.2 Data conformance

a) Test purpose: to verify an adequate application class for the expression of an optics sensor, radiometry.

b) Test method: inspect the documentation of the application schema or profile and exhibit the required correspondence.

c) References: 6.3, including the following data types and code lists:

1) CA_Method, 6.3.10;

2) CA_TonalAdjustment, 6.3.11;

3) CA_RadiometricTransformation, 6.3.12;

4) CA_LUT, 6.3.13;

5) CA_Linearity, 6.3.18;

6) CA_RadiometricDynamics, 6.3.19;

7) CA_SpectralSensitivity, 6.3.20;

8) CA_PointSpreadFunction, 6.3.21;

9) CA_SamplingPattern, 6.3.22;

10) CA_Spectrum, 6.3.23;

11) CA_DynamicRange, 6.3.24;

12) CA_DefectPixels, 6.3.29;

13) CA_ErrorType, 6.3.30.

A.5 Calibration Facility Geometry

A.5.1 Service conformance

a) Test purpose: to verify the use of the appropriate interface for a calibration facility, geometry service.

b) Test method: inspect the documentation of the service interface to verify the use of interfaces defined in the references in c).

c) References: 6.4.1 to 6.4.8.

A.5.2 Data conformance

a) Test purpose: to verify an adequate application class for the expression of a calibration cacility, geometry.

b) Test method: inspect the documentation of the application schema or profile and exhibit the required correspondence.

c) References: 6.4, including the following data types and code lists:

1) CA_PositionalError, 6.4.9;

2) CA_PointType, 6.4.10;

3) CA_QuantityType, 6.4.11;

4) CA_PointSuspension, 6.4.12;

5) CA_InstrumentType, 6.4.13;

6) CA_GeometricTargetType, 6.4.14.

A.6 Calibration Facility Radiometry

A.6.1 Service conformance

a) Test purpose: to verify the use of the appropriate interface for a calibration facility, radiometry service.

b) Test method: inspect the documentation of the service interface to verify the use of interfaces defined in the references in c).

c) References: 6.5.1 to 6.5.9.

A.6.2 Data conformance

a) Test Purpose: to verify an adequate application class for the expression of a Radiometry Recording.

b) Test Method: inspect the documentation of the application schema or profile and exhibit the required correspondence.

c) References: 6.5, including the following data types:

   1) CA_CalibrationMethod, 6.5.10;

   2) CA_RadiometricTargetShape, 6.5.11;

   3) CA_RadiometricTargetMaterial, 6.5.12;

   4) CA_MeasuredReflectance, 6.5.13;

   5) SD_Calibration, 6.5.14.

A.7 Validation

A.7.1 Service conformance

a) Test purpose: to verify the use of the appropriate interface for a validation service.

b) Test method: inspect the documentation of the service interface to verify the use of interfaces defined in the reference in c).

c) Reference: 6.6.

A.7.2 Data conformance

a) Test purpose: to verify an adequate application class for the expression of a validation.

b) Test method: inspect the documentation of the application schema or profile and exhibit the required correspondence.

c) References: 6.6, including the following data types:

   — CA_ValidationMethod, 6.6.3.

A.8 Documentation

A.8.1 Data conformance

a) Test purpose: to verify an adequate application class for the expression of a documentation.

b) Test method: inspect the documentation of the application schema or profile and exhibit the required correspondence.

c) References: 7.2, including the following data types:

— CA_DataProductLevel, 7.2.3.

Annex B
(normative)

Data dictionary

B.1 General

Annex B provides a detailed description of each of the classes and each class attribute in the models presented in this Technical Specification in the form of a tabular data dictionary.

B.2 Semantics

	Name/role name	Definition	Obligation/ condition	Max. occurrence	Data type/ class	Domain
1.	CA_CalibrationValidation 6.1.2	root entity that defines information about calibration	Use obligation/ condition from referencing object	Use maximum occurrence from refe rencing object	Aggregated Class (MD_Coverage Description)	
2.	calibrationType	characterization of the calibration coded with the data type CA_CalibrationType	M	1	CA_Calibration Type	
3.	CA_PhotoFlight 6.1.3	information about the photo flight that was performed to derive the calibration results from	Use obligation/ condition from referencing object	Use maximum occurrence from refe rencing object	Aggregated Class (CA_Calibration Validation)	
4.	numberOfPhoto Flights	quantity of photo flights that are taken for performing the calibration	M	1	Integer	
5.	photoScale	average photo scale of the calibration project	M	N	Real	0,0 to 1,0
6.	flyingHeight	average height of the sensor platform above the reference height plane	M	N	Length	
7.	flyingAltitudeAbove Ground	average height of the sensor platform above the ground	M	N	Length	
8.	terrainHeight	average height of the terrain where the calibration is performed NOTE The terrain height is modelled as one value because it is an aggregate value which is often for information purposes or as an approximate value.	M	1	Length	

	Name/role name	Definition	Obligation/ condition	Max. occurrence	Data type/ class	Domain
9.	alongStripOverlap	approximate value for the along strip overlap of the photogrammetric block. NOTE The attribute values are given in percent.	M	N	Real	0,0 to 100,0
10.	acrossStripOverlap	approximate values for the across strip overlap of the photogrammetric block. NOTE The attribute values are given in percent.	M	N	Real	0,0 to 100,0
11.	Base	approximate distance between two neighbouring photos	M	N	Length	
12.	numberOfPhotos	total number of photos of the photogrammetric block	M	1	Integer	
13.	numberOfStrips	total number of strips of the photogrammetric block	M	1	Integer	
14.	numberOfPhotos Along Strip	total number of photos in one strip of the photogrammetric block	M	1	Integer	
15.	numberOfPhotos Used	number of photo used for processing the calibration	M	1	Integer	
16.	CA_Radiation 6.1.4	information that is necessary to describe the radiative environment during the calibration process	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (CA_Calibration Validation)	
17.	solarZenithAngle	angle from the zenith towards the sun	M	1	Angle	0,0 to 90,0
18.	solarAzimuth	horizontal angle to the sun counted counterclockwise from North	M	1	Angle	0,0 to 360,0
19.	atmosphericCondition	general description of the status of the atmosphere during the calibration	M	1	CharacterString	
20.	atmosphericModel	characterization of the atmospheric model Examples of character strings defining the attribute are 6sv1.1 (), acorn (), actor (), atrem (), disort (), flash (), modtran (), modtran4 (), modtran5 (), sbdart (), smac (), and tafkaa ().	M	1	CharacterString	
21.	modelType	characterization of the BRDF model (Bi-directional Reflectance Distribution Function)	M	1	CI_Citation	

	Name/role name	Definition	Obligation/ condition	Max. occurrence	Data type/ class	Domain
22.	solarIncidentAngle	definition of the angle which is calculated from solar zenith angle, solar elevation angle, target azimuth, and the target Inclination	M	1	Angle	
23.	solarIrradiance	irradiance of the sun	O	1	CA_Irradiance Model	
24.	CA_Target 6.1.5	information necessary to describe the targets used during the calibration process	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (CA_Calibration Validation)	
25.	Equipment	description of additional equipment, for example measurement instruments	M	1	CharacterString	
26.	targetInclination	inclination (slope) of a ground target	M	1	Angle	0,0 to 90,0
27.	targetAzimuth	azimuth of the steepest inclination of the ground target	M	1	Angle	0,0 to 360,0
28.	targetAltitude	ground elevation of the target NOTE This attribute does not regard vegetation and man-made objects.	M	1	Length	
29.	skyViewFactor	the portion of the sky that is visible from the ground target	M	1	Real	0,0 to 100,0
30.	Viewshed	area that is visible from a fixed vantage point NOTE The attribute value is a name of a file that provides a two-dimensional representation of the viewshed.	M	1	CharacterString	
31.	targetEnvironment	characterization of the environment of a target, namely homogeneous or inhomogeneous	M	1	CA_target Environment	
32.	targetAccessibility	accessibility of the target primarily regarding road condition and eventual seasonal changes	M	1	CharacterString	
33.	targetStability	description of the mechanical stability of the target depending on weather conditions like humidity, heat, and wind	M	1	CharacterString	

	Name/role name	Definition	Obliga-tion/ condition	Max. occur-rence	Data type/ class	Domain
34.	transmittanceSunTo Target	description of the amount of radiation transmitted from the sun to a target on Earth measured in a part of one hundred	M	1	Real	0,0 to 100,0
35.	transmittanceTar-getTo Satellite	description of the amount of radiation transmitted from a target on Earth to the satellite measured in a part of one hundred	M	1	Real	0,0 to 100,0
36.	sunRadiationAt-TopOf Atmosphere	description of the amount of radiation transmitted from the sun to the top of the atmosphere of Earth measured in a part of one hundred	M	1	Real	0,0 to 100,0
37.	radianceAtSatellite	description of the amount of radiation received at the satellite measured in a part of one hundred	M	1	Real	0,0 to 100,0
38.	CA_OpticalSensors 6.1.6	top level class for all calibration information of optical sensors	Use obliga-tion/ con-dition from referencing object	Use maximum occurrence from refer-encing object	Specified abstract Class (CA_Calibra-tion Validation)	

B.3 Package OpticsSensor: Geometry

	Name/role name	Definition	Obliga-tion/ condition	Max. occur-rence	Data type/ class	Domain
39.	CA_OpticsSensor Geometry 6.2.2		Use obliga-tion/ con-dition from referencing object	Use maximum occurrence from refer-encing object	Specified Class (CA_Optical Sensor)	
40.	geometryCalibra-tionDate	the time when the calibra-tion was performed	O	N	DateTime	
41.	geometryCalibra-tionType	free text that allows a more detailed explanation of the type defined with CA_CalibrationType	O	N	Character-String	
42.	CA_InteriorOrienta-tion 6.2.3	details of the geometry of the sensor system includ-ing the auxiliary devices relevant for a geometric calibration	Use obliga-tion/ con-dition from referencing object	Use maximum occurrence from refer-encing object	Specified Class (CA_OpticsSen-sorGeometry)	
43.	synchronization	time between two pulses for the synchronization of the work of the attached components	M	1	DateTime	
44.	synchronizationEr-ror	error of the attribute syn-chronization	M	1	DateTime	

	Name/role name	Definition	Obligation/ condition	Max. occurrence	Data type/ class	Domain
45.	referenceTemperature	temperature for which the calibration is performed	M	1	CA_Temperature	
46.	versionFirmware	note about the firmware version	M	1	CharacterString	
47.	versionHardware	note about the hardware version	M	1	CharacterString	
48.	CA_SensorSystem 6.2.4	details of a multihead sensors system	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Interior Orientation)	
49.	relativePosition	position of the origin of the coordinate system of a camera head in relation to the coordinate system of the sensor system	M	1	DirectPosition	
50.	relativeAttitude	rotation of the coordinate system of a camera head in relation to the coordinate system of the sensor system	M	1	SD_Attitude	
51.	stitchingResiduals	geometric error remaining after stitching the multi camera-head images to one large image	M	1	Length	
52.	operationalTemperature	temperature range for which the calibration is valid	M	1	CA_Temperature Range	
53.	SD_Optics 6.2.5	specific properties of optical sensor and its operation	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (CA_Sensor System)	
54.	CA_Optics 6.2.6	information necessary to characterize the optical sensor system (camera) that is not defined in the class SD_Optics of ISO/ TS 19130	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (SD_Optics)	
55.	cameraHead	description of the respective camera head	M	1	CharacterString	
56.	channel	description of the available spectral channels	M	1	CharacterString	
57.	SD_OpticalSystem 6.2.7	information about the geometry of the sensor's optical system	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (SD_ Optics)	
58.	calibratedFocalLength	focal length adjusted to distribute the effects of lens distortion more uniformly over the image	M	1	Length	

	Name/role name	Definition	Obligation/ condition	Max. occurrence	Data type/ class	Domain
59.	qualityOfCalibratedFocalLength	quality of the calibrated focal length	O	1	DQ_Quantitative AttributeAccuracy	
60.	princPointAutocoll	principal point of autocollimation; coordinates of the foot of the perpendicular dropped from perspective centre (focal point) of the camera lens to the focal plane.	M	1	DirectPosition	
61.	covPrincPtAutocoll	covariance of the location of the principal point of autocollimation	O	1	DQ_Positional Accuracy	
62.	CA_OpticalSystem 6.2.8	information of an optical sensor system that is necessary for the geometric calibration and that is not defined in ISO/TS 19130	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (SD_Optical System)	
63.	resolvingPower	definition of the resolving power of the optical system	M	1	CA_Geometric Resolution	
64.	virtualFocalLength	definition of the computed focal length of a camera system with two or more camera heads NOTE Several digital photogrammetric cameras consist of two of more separate cameras, often called camera-heads, that are firmly attached by a robust frame. Before delivery the separate images are resampled to a homogeneous large image. This large image is equipped with one focal length that approximates the joint image geometry of the two or more original images. This focal length is named the virtual focal length.	M	1	Length	
65.	virtualSensorSize	definition of the computed full sensor size of a camera system with two or more camera heads	M	1	Length	
66.	virtualPixelSize	definition the computed pixel size of a camera system with two or more camera heads	M	1	Length	
67.	virtualPrinciplePoint Autocoll	definition of the computed principle point of autocollimation of a camera system with two or more camera heads	M	1	DirectPosition	

	Name/role name	Definition	Obligation/ condition	Max. occurrence	Data type/ class	Domain
68.	SD_DetectorArray 6.2.9	dimensions and shapes of detector array	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (SD_Optics)	
69.	numberOfDimensions	number of dimensions of the detector array	M	1	Integer	
70.	arrayOrigin	position of the origin of the detector array coordinate system in external coordinate system	M	1	DirectPosition	
71.	arrayDimensions	names and sizes of the dimensions of the detector array	M	2	SD_Array Dimension	
72.	offsetVectors	displacement between origin of the detector array coordinate system and the location of the first detector in the detector array	M	2	Vector	
73.	detectorSize	size of a detector in a detector array dimension specified by detectorDimensionName	M	2	Length	
74.	detectorShape	shape of a detector	M	1	SD_ShapeCode	
75.	distortion	distortion of detector array	O	1	SD_Distortion	
76.	CA_GeometricPre Correction 6.2.10	information about the geometric modification of the image data during the processing from the status raw-data to the status first original	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (SD_Optics)	
77.	polynomialDegree	definition of the power of the polynomial	M	1	Integer	≥0
78.	polynomialCoefficients	definition of the coefficients of the polynomial	O	N	Real	
79.	resamplingDate	definition of the time of processing	M	1	DateTime	
80.	parameters	definition of all other involved parameters	O	N	Real	
81.	CA_AuxiliaryDevice 6.2.11	superclass for CA_GNSS and CA_IMU GNSS and IMU are auxiliary devices for the measurement of position and attitude of moving platforms.	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Interior Orientation)	
82.	timeLeverarm	time when the leverarm was calibrated	M	1	DateTime	

	Name/role name	Definition	Obligation/ condition	Max. occurrence	Data type/ class	Domain
83.	leverarm	definition of the position-vector from the GNSS-reference point to the reference point of the sensor system, e.g. the projection centre of the camera, given in the Coordinate Reference System of the platform.	M	1	DirectPosition	
84.	errorLeverarm	definition of the error of the leverarm	M	1	Length	
85.	CA_GNSS 6.2.12	information about the satellite navigation that is relevant for the calibration	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Auxiliary Device)	
86.	numberSatellites	minimum number of satellites that is necessary for performing a calibration measurement	M	1	Integer	≥4
87.	registrationCycle	longest allowed temporal interval between two position measurements made by the GNSS	M	1	DateTime	
88.	CA_IMU 6.2.13	information about the Inertial Measurement Unit (IMU) that is relevant for the calibration	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Auxiliary Device)	
89.	boresightAngle	three angles that define the rotation between the coordinate reference system of the sensor system, e.g. the camera, and the coordinate reference system of the IMU	M	1	SD_Attitude	
90.	dataRate	temporal interval between two registrations	M	1	DateTime	
91.	attitudeAccuracy	quality of an angular measurement	M	1	Angle	
92.	SD_Distortion 6.2.19	defined in ISO/TS 19130; superclass of the classes SD_DistortionTable, SD_DistortionPolynomial, and CA_Distortion.	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (SD_Optics)	
93.	princPointOfSymmetry	position of the principle point of symmetry	M	1	DirectPosition	
94.	qualityOfPrincPointOf Symmetry	Quality of the principle point of symmetry	M	1	DQ_QuantitativeAttributeAccuracy	

	Name/role name	Definition	Obligation/ condition	Max. occurrence	Data type/ class	Domain
95.	SD_DistortionTable 6.2.20	distortion information in a tabular form and is defined in ISO/TS 19130	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (SD_Distortion)	
96.	rows	number of rows of the distortion table	M	1	int	≥1
97.	columns	number of columns of the distortion table	M	1	int	≥1
98.	xOffset	image column number corresponding to the first cell in the table	M	1	int	≥0
99.	yOffset	image row number corresponding to the first cell in the table	M	1	int	≥0
100.	xSpacing	number of columns in the image corresponding to an interval of one table column	M	1	int	
101.	ySpacing	number of rows in the image corresponding to an interval of one table row	M	1	int	
102.	distortionValues	array of values describing image distortion	M	N	float	
103.	SD_Distortion Polynomial 6.2.21	distortion described using a polynomial.	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (SD_Distortion)	
104.	polynomialDecentering	polynomial that describes decentering distortion	O	1	SD_PolynomialFunction	
105.	polynomialRadial	polynomial that describes radially symmetrical distortion	O	1	SD_PolynomialFunction	
106.	qualityOfPolynomialRadial	covariance of the polynomial coefficients for radial distortion	O	1	DQ_PositionalAccuracy	
107.	qualityOfPolynomialDecentring	covariance of the polynomial coefficients for decentering distortion	O	1	DQ_PositionalAccuracy	
108.	CA_Distortion Polynomial 6.2.22	information about the polynomial distortion model that is not defined in the class SD_DistortionPolynomial	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (SD_Distortion Polynomial)	
109.	polynomialDegree	power of distortion polynomial	M	1	Integer	≥0
110.	polynomialCoefficients	coefficients of the distortion polynomial, i.e. polynomialCoefficients = (polynomialDegree + 1) * (polynomialDegree + 2)	O	1	Real	

	Name/role name	Definition	Obligation/ condition	Max. occurrence	Data type/ class	Domain
111.	thinSplineDegree	power of the thin spline	M	1	Integer	≥0
112.	thinSplineCoefficients	coefficients of the thin spline	O	1	Real	
113.	CA_Distortion 6.2.23	distortion information necessary for the geometric calibration of an optical camera that is not covered by ISO/TS 19130.	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (SD_Distortion)	
114.	selfCalibrationModel	name of the self-calibration model with details defined in the data type CA_SelfCalibrationModel	M	1	CA_SelfCalibrationModel	
115.	radialDistortion	distortion developed along a radius from the centre of the image	M	1	CA_Radial Distortion	
116.	deceneringDistortion	distortion caused by a misalignment of the lens elements	M	1	CA_Decentering Distortion	
117.	affineDistortion	distortion that can be compensated by an affine transformation	M	1	CA_AffineDistortion	
118.	tangentialDistortion	distortion developed normal to a radius from the centre of the image	M	1	CA_Tangential Distortion	
119.	affineFraserDistortion	distortion that can be compensated by the Fraser model (see C.3)	M	1	CA_Affine-Fraser Distortion	
120.	smacParameters	distortion that can be compensated by the SMAC model (see C.4)	M	1	CA_SMAC Parameters	
121.	ebnerParameters	distortion that can be compensated by the Ebner model (see C.5)	M	1	CA_Ebner Parameters	
122.	jacobsenParameters	distortion that can be compensated by the Jacobsen model (see C.6)	M	1	CA_Jacobsen Parameters	
123.	software	name of the software product applied for the calibration processing	M	1	CharacterString	
124.	propertiesAlgorithm	name and the properties of the algorithm that is programmed in the software	M	1	CharacterString	
125.	sigmaNaught	overall error of the calibration processing	M	1	Length	
126.	CA_RadialDistortion 6.2.25	data type with the K-values for describing the radial distortion	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	dataType	
127.	numberCoefficients	quantity of values applied	M	1	Integer	≥0

	Name/role name	Definition	Obligation/ condition	Max. occurrence	Data type/ class	Domain
128.	k	coefficients of the radial distortion model	O	N	Real	
129.	CA_Decentering Distortion 6.2.26	data type with the P-values for describing the decentering distortion of the SMAC-model	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	dataType	
130.	p1	first coefficient of the description of the decentering distortion	M	1	Real	
131.	p2	second coefficient of the description of the decentering distortion	M	1	Real	
132.	CA_Tangential Distortion 6.2.28	data type with the T-values for describing the tangential distortion of the Brown- and the Fraser-model	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	dataType	
133.	t1	first coefficient of the description of the tangential distortion	M	1	Real	
134.	t2	second coefficient of the description of the tangential distortion	M	1	Real	
135.	CA_AffineDistortion 6.2.27	data type with the A-values for describing the affine distortion of the Brown-model	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	dataType	
136.	a1	first coefficient of the description of the affine distortion	M	1	Real	
137.	a2	second coefficient of the description of the affine distortion	M	1	Real	
138.	CA_AffineFraser Distortion 6.2.29	data type with the F-values for describing the affine distortion of the Fraser-model	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	dataType	
139.	f1	first coefficient of the description of the affine fraser distortion	M	1	Real	
140.	f2	second coefficient of the description of the affine fraser distortion	M	1	Real	
141.	CA_EbnerParameters 6.2.31	data type with the 12 Ebner-parameters (e_1 until e_{12})	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	dataType	
142.	e	coefficients of the Ebner model	M	12	Real	

	Name/role name	Definition	Obliga-tion/ condition	Max. occur-rence	Data type/ class	Domain
143.	CA_Jacobsen Parameters 6.2.32	data type with the 15 Jacobsen parameters (j_1 until j_{15}) NOTE The distortion model of Jacobsen defines parameters from j1 until j_{88}. However, only the first 15 are normative because the further have a product-specific meaning	Use obliga-tion/ con-dition from referencing object	Use maximum occurrence from refer-encing object	dataType	
144.	j	coefficients of the Jacobsen model	M	15	Real	

B.4 Package OpticsSensor: Radiometry

	Name/role name	Definition	Obliga-tion/ Condition	Max. occur-rence	Data type/ class	Domain
145.	CA_OpticsSensor Radiometry 6.3.2	information about the radiometric calibration	Use obliga-tion/ con-dition from referencing object	Use maximum occurrence from refer-encing object	Specified Class (CA_Optical Sensor)	
146.	case	definition one of the cases: 1: Lsensor(i,j) = k*DN(i,j) + d 2: L = (DN-1)*UCC 99: None of those formulae	M	1	Integer	1, 2, 99
147.	numberOfPieces	number of pieces in the case of a piecewise linear transformation	M	1	Integer	≥0
148.	gain	gain of the curve	M	N	Real	
149.	offset	offset of the curve	M	N	Distance	
150.	signOfGain	sign of the gain	M	N	Real	1 = plus −1 = minus
151.	minWavelength	minimum wavelengths for which the respective gain is valid	M	N	Length	
152.	maxWavelength	maximum wavelengths for which the respective offset is valid	M	N	Length	
153.	b	correction parameter for compensating the effect of path radiance and illumination factors such as sky light and reflected radiance	M	N	Real	

	Name/role name	Definition	Obligation/ Condition	Max. occurrence	Data type/ class	Domain
154.	c	correction parameter for compensating the effect of path radiance and illumination factors such as sky light and reflected radiance	M	N	Real	
155.	CA_RadiometryOff Sensor 6.3.3	information regarding influences on the radiometry not generated by the sensor	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Optics-SensorRadiometry)	
156.	atmosphericModel	model that is applied for the atmospheric correction.	M	1	Character-String	
157.	modelProperties	general description of the atmospheric model	M	1	Character-String	
158.	method	method applied for the atmospheric correction	M	1	CA_Method	
159.	illumination	definition of the light conditions of the imaged object	M	1	Character-String	
160.	pathRadiance	definition of the amont of radiation that is added to the received total radiation by influences located along the track	M	1	Real	0,0 to 100,0
161.	backgroundRadiance	description of the amont of radiation that is added to the received total radiation by influences from any background	M	1	Real	0,0 to 100,0
162.	skylight	description of the amount of radiation received as scattered solar radiation from the atmosphere measured in a part of one hundred	M	1	Real	0,0 to 100,0
163.	skylightReflected	description of the amount of radiation received as scattered solar radiation from the atmosphere and then reflected from adjacent objects such as buildings or the ground measured in a part of one hundred	M	1	Real	0,0 to 100,0
164.	CA_RadiometryIn Sensor 6.3.4	information regarding influences on the radiometry generated by the sensor	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Optics-SensorRadiometry)	
165.	SensorSystem Identification	identification of the sensor system	M	1	MD_Identification	

	Name/role name	Definition	Obligation/ Condition	Max. occurrence	Data type/ class	Domain
166.	CA_OptoElectronic System 6.3.5	information necessary for the radiometric calibration of an opto-electronic system	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Radiometry InSensor)	
167.	numberSensor-Heads	definition of the number of sensors that make up the system	M	1	Integer	≥1
168.	CA_Sensor Measurement 6.3.6	information about the measurement methods applied for determining any of the calibrated parameters	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Opto ElectronicSystem)	
169.	measurement-Method MTF	definition of the measurement method for the determination of the modulation transfer function	M	1	Character-String	
170.	measurement-Method PSF	definition of the measurement method for the determination of the point spread function	M	1	Character-String	
171.	CA_SensorPost Processing 6.3.7	information about image modifications during post processing	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Opto ElectronicSystem)	
172.	colourTransformation	coefficients that are used to perform a colour transformation	M	1	Character-String	
173.	CA_RadiometryPre Correction 6.3.8	information about the radiometric modification of the image data during the processing from the status raw-data to the status first original	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (CA_Opto ElectronicSystem)	
174.	resamplingDate	time of processing	M	1	DateTime	
175.	tonalAdjustment-Type	type of tonal adjustment	M	1	CA_Tonal Adjustment	
176.	gammaCorrection	amount of the gamma correction	M	1	Real	≥0,0
177.	radiometric Transformation	definition the change of the grey value depth	M	1	CA_Radiometric Transformation	
178.	lookUpTable	definition a look-up-table for a radiometric change of the image	M	1	CA_LUT	
179.	filterType	filter applied for the radiometric change	M	1	CI_Citation	
180.	parameters	definition other involved parameters	O	N	Real	

	Name/role name	Definition	Obligation/ Condition	Max. occurrence	Data type/ class	Domain
181.	CA_OpticalFilters 6.3.9	information about the optical filters involved	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Clas (CA_Radiometry InSensor)	
182.	spectralCharacteristics	transmission-curve of the filter	M	1	CA_Spectrum	
183.	CA_DefectPixels 6.3.30	data type that defines the row and the column of a defect (incorrectly responding) pixel	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	dataType	
184.	row	definition of the row of a defect (incorrectly responding) pixel	M	1	Integer	≥0
185.	column	definition of the column of a defect (incorrectly responding) pixel	M	1	Integer	≥0
186.	CA_Linearity 6.3.19	data type that defines the linearity of the sensor response. NOTE The value-pairs receivedIntensity – recordedIntensity define the response-curve of the sensor.	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	dataType	
187.	channelIdentification	alpha-numerical identification for the channel	M	1	CharacterString	
188.	receivedIntensity	radiometric activation of the sensor	O	N	Real	0,0 to 100,0
189.	recordedIntensity	recorded intensity	O	N	Real	0,0 to 100,0
190.	CA_Radiometric Dynamics 6.3.20	data type that defines a bit-value specifying the number of greyvalue steps within the radiometric range	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	dataType	
191.	bit	number of bits within the range	M	1	Integer	≥1
192.	CA_SpectralSensitivity 6.3.21	data type that defines the spectral range based on wavelengths	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	dataType	
193.	minimumWavelength	lower border of the range	M	1	Length	
194.	maximumWavelength	upper border of the range	M	1	Length	
195.	sensitivityFunction	function that relates the received radiation to the sensor’s response	M	1	CharacterString	

	Name/role name	Definition	Obligation/ Condition	Max. occurrence	Data type/ class	Domain
196.	CA_LUT 6.3.13	data type that defines a look-up-table	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	dataType	
197.	identification	Characterization of the LUT	M	1	CharacterString	
198.	in	value in the input column	O	N	Integer	≥0
199.	out	value in the input column	O	N	Integer	≥0
200.	CA_Sensor Characteristics 6.3.14	information about the sensor	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Opto ElectronicSystem)	
201.	sensorIdentification	identification of the sensor	M	1	MD_Identification	
202.	cameraHead	camera or sensor head for which the information is valid	M	1	CharacterString	
203.	channel	channel for which the information is valid	M	1	CharacterString	
204.	CA_SensorParameters 6.3.15	information that characterizes the imaging performance of the sensor	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Sensor Characteristics)	
205.	pointSpreadFunction	Point Spread Function (PSF) of the sensor	M	1	CA_PointSpread Function	
206.	fNumberDenominator	denominator of the aperture of the sensor	M	1	Integer	≥1
207.	samplingPattern	shape of a ground pixel	M	1	CA_Sampling Pattern	
208.	spectralResponse	spectral response characteristics of the sensor	M	1	CA_Spectrum	
209.	CA_SensorQuality Evaluation 6.3.16	information about the radiometric quality of the sensor	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Sensor Characteristics)	
210.	linearity	definition of the spectral response-curve of the sensor	M	1	CA_Linearity	
211.	absoluteSpectralError	definition of the difference between two radiometric measurements under the same off-sensor conditions	M	1	Integer	
212.	relativeSpectralError	definition of the difference between two radiometric measurements under the same off-sensor conditions	M	1	Real	0,0 to 100,0

	Name/role name	Definition	Obligation/ Condition	Max. occurrence	Data type/ class	Domain
213.	dynamicRange	definition of the range of distinguishable grey values of the sensor NOTE The dynamic range has the data type integer and is computed from the distinguishable digital numbers (DN) as follows: $n[dB] = 20 \log DN$ or $DN = 10^{\frac{n[dB]}{20}}$ where *n* is the dynamic range *DN* is the effective digital numbers	M	1	CA_DynamicRange	
214.	spectralSensitivity	definition of the spectral sensitivity of the sensor	M	1	CA_Spectral Sensitivity	
215.	signalToNoiseRatio	characterization of the noise of the sensor	M	1	CA_Radiometric Dynamics	
216.	illuminationLevel	definition of the illumination level for which the attribute signalToNoiseRatio is valid NOTE The unit of illuminationLevel is watts per square metre (1lx = 1lm/m^2).	M	1	Real	≥0,0
217.	modulationTransfer Function	definition of the Modulation Transfer Function (MTF) of the sensor	O	N	Real	≥0,0
218.	modulationTransfer FunctionAcross	definition of the Modulation Transfer Function (MTF) of the sensor across the flight-track	O	N	Real	≥0,0
219.	modulationTransfer FunctionAlong	definition of the Modulation Transfer Function (MTF) of the sensor along the flight-track	O	N	Real	≥0,0
220.	positionInImage	positions in the image to which the MTF-values are related NOTE The MTF is defined as a matrix with m rows and n columns. This attribute is a vector of those mxn positions.	O	N	DirectPosition	
221.	polarization	definition of the polarization characteristics of the sensor	M	1	Character-String	

	Name/role name	Definition	Obligation/ Condition	Max. occurrence	Data type/ class	Domain
222.	radiometricDynamics	definition of the number of distinguishable grey values	M	1	CA_Radiometric Dynamics	
223.	antiBlooming	information whether a sensor is equipped with anti-blooming techniques or not	M	1	Boolean	1 = yes 0 = no
224.	CA_SensorDefects 6.3.17	information about the defects of the sensor	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Sensor Characteristics)	
225.	colourAberration	definition of a geometric bias of the co-registration of the colour channels	M	1	CharacterString	
226.	strayLight	definition of the amount of stray light of the sensor	M	1	CharacterString	
227.	residualPolarization	definition of the non-compensated parts of the polarization	M	1	CharacterString	
228.	smile	description of the smile distortion of the optical system	M	1	CharacterString	
229.	keystoneEffect	description of the presence of the keystone effect NOTE This effect is caused by the perspective transformation that is applied while the imaging of an object with an optical sensor that is based on the central perspective.	M	1	Boolean	1 = yes 0 = no
230.	CA_Detector 6.3.25	information necessary to identify a detector	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Opto ElectronicSystem)	
231.	detectorIdentification	information necessary to identify the detector	M	1	MC_Identification	
232.	CA_ElectronicCell 6.3.26	information necessary for the radiometric calibration regarding a detector element or a detector array	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Detector)	
233.	sensitivity	response of an individual detector element relative to the activation	M	1	CharacterString	
234.	pixelResponseNon Uniformity	inhomogenities of the response of the detectors of a detector array to activation NOTE The attribute is abbreviated with PRNU.	M	1	CharacterString	

	Name/role name	Definition	Obligation/ Condition	Max. occurrence	Data type/ class	Domain
235.	darkSignalNonUniformity	response of a detector element if no visible or infrared light is present NOTE This activation is mostly caused by imperfection of the detector. The attribute is abbreviated with DSNU.	M	1	CharacterString	
236.	errorTypeDarkSignalNonUniformity	type of error of the attribute darkSignalNonUniformity	M	1	CA_ErrorType	
237.	errorDarkSignalNon Uniformity	relative error of the attribute darkSignalNonUniformity	M	1	Real	≥0
238.	defectPixels	image-position of a defect pixel	M	1	CA_DefectPixels	
239.	defectPixelsBright Image	image-position of a defect pixel that is defect if the activation is intense (bright image)	M	1	CA_DefectPixels	
240.	defectPixelsDarkImage	image-position of a defect pixel that is defect if the activation is low (dark image)	M	1	CA_DefectPixels	
241.	artifacts	description of other deficiencies of the detector	M	1	CharacterString	
242.	CA_DetectorOptics 6.3.27	information necessary to describe the optics of a detector	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Detector)	
243.	lightFalloff	decrease of activation of detector elements toward the border/end of the detector array due to the imperfection of the lens NOTE This is also called vignetting. The measurement is done in the laboratory using a uniform light source to create a sensitivity profile.	M	1	CharacterString	
244.	CA_DetectorDemands 6.3.28	threshold values for the quality parameters found in the calibration process	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Electronic Cell)	
245.	maximumAllowedDefectPixels	maximum allowed number of defect pixels on the entire sensor	M	1	Integer	≥0

	Name/role name	Definition	Obligation/ Condition	Max. occurrence	Data type/ class	Domain
246.	maximumAllowedDefectPixelsDoubleColumn	maximum allowed number of defect pixels on a pair of columns	M	1	Integer	≥0
247.	maximumAllowedDefectPixelsSingleColumn	maximum allowed number of defect pixels on a single column	M	1	Integer	≥0

B.5 Package OpticsCalibrationFacility: Geometry

	Name/role name	Definition	Obligation/ condition	Max. occurrence	Data type/ class	Domain
248.	CA_OpticsFacility Geometry 6.4.2	information related to a calibration laboratory and to an in-flight calibration	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Optical Sensor)	
249.	CA_InFlight 6.4.3	abstract superclass of the classes CA_GeometricTarget and CA_TestRange	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Optics FacilityGeometry)	
250.	CA_GeometricTarget 6.4.4	information about the targets	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_InFlight)	
251.	size	the width of the two-dimensional bounding box around the target	M	1	Length	
252.	description	free text description of the target	M	1	CharacterString	
253.	type	characteristic of the target according to the code list set in the class CA_GeometricTargetType	M	1	CA_Geometric TargetType	
254.	material	substance of the target's surface such as paint or awning	M	1	CA_Radiometric TargetMaterial	
255.	paintType	characteristics of the paint	M	1	CharacterString	
256.	reflectanceProperties	peculiarity of the reflectance	M	1	CharacterString	
257.	CA_Siemensstar 6.4.5	information about a target of type Siemens star	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Geometric Target)	
258.	diameter	length of two radiuses of the Siemens star	M	1	Length	

	Name/role name	Definition	Obligation/ condition	Max. occurrence	Data type/ class	Domain
259.	sector	angular width of the Siemens star Example: if the attribute value is 180°, then the Siemens star is drawn as a semicircle.	M	1	Angle	0,0 to 360
260.	numberOfBarsInSector	partitioning of the sector. The attribute defines a bar-pair. A bar-pair is a white sector and a black sector. Example: if the attribute sector is set to 180° and the attribute numberOfBarsInSector has a value of 10, then the Siemens star has 10 white and 10 black sections with an angular width of 9° each.	M	1	Integer	>0
261.	CA_AirforcePattern 6.4.6	information about the target of type airforce pattern NOTE 1: An airforcepattern has a set of white and black target-bars with variable widths. NOTE 2: The sections of the airforce pattern are called boxes.	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Geometric Target)	
262.	minimumBarWidth	smallest width of a target-bar	M	1	Length	
263.	maximumBarWidth	widest width of a target-bar	M	1	Length	
264.	numberOfBarsInBox	quantity of bars in one box	M	1	Integer	>0
265.	numberOfBoxes	quantity of all boxes	M	1	Integer	>0
266.	CA_TestRange 6.4.7	information valid to describe the entire test range	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_InFlight)	
267.	controlPoint	position of control points	O	N	DirectPosition	
268.	checkPoint	position of check points	O	N	DirectPosition	
269.	numberControlPoints	quantity of control points	M	1	Integer	≥0
270.	numberCheckPoints	quantity of check points	M	1	Integer	≥0

	Name/role name	Definition	Obligation/ condition	Max. occurrence	Data type/ class	Domain
271.	groundSampleDistance	smallest Ground Sample Distance (GSD) that can sensibly be applied for a sensor calibration on this test range NOTE The targets have a given size. Therefore they may not be small enough to be used for a calibration process with a smaller GSD than stated in the attribute groundSampleDistance.	M	1	Length	
272.	minimumElevation	smallest elevation of a target of the test range	M	1	Length	
273.	maximumElevation	highest elevation of a target of the test range	M	1	Length	
274.	averageElevation	average elevation of targets of the test range NOTE The average elevation should be computed as the arithmetic mean of all targets.	M	1	Length	
275.	positionalError	geometric accuracy of the test range	O	N	CA_PositionalError	
276.	lengthOfTestrange	length of larger edge of bounding box of test range	M	1	Length	
277.	widthOfTestrange	length of smaller edge of bounding box of test range	M	1	Length	
278.	elevationChangeOfTestrange	elevation range of test range	M	1	Length	
279.	CA_Laboratory 6.4.8	information related to the instruments utilized during the calibration	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Optics FacilityGeometry)	
280.	calibrationInstrument	type of calibration instrument coded with the data type CA_InstrumentType	M	1	CA_InstrumentType	
281.	pointSuspension	method of attaching control points and check points to a fundament	M	1	CA_PointSuspension	
282.	CA_PositionalError 6.4.9	data type that specified the positional error of a point	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	dataType	
283.	errorX	geometric accuracy regarding the x-dimension	M	1	Length	
284.	errorY	geometric accuracy regarding the y-dimension	M	1	Length	
285.	errorZ	geometric accuracy regarding the z-dimension	M	1	Length	

	Name/role name	Definition	Obligation/ condition	Max. occurrence	Data type/ class	Domain
286.	errorXY	geometric accuracy regarding the xy-plane	M	1	Length	
287.	errorXYZ	geometric accuracy regarding the 3-dimensional space	M	1	Length	
288.	pointType	characterization of the point coded with the data type CA_PointType	M	1	CA_PointType	
289.	errorType	characterization of the error coded with the data type CA_ErrorType	M	1	CA_ErrorType	
290.	quantityType	information about the meaning of the error coded in the attribute CA_QuantityType	M	1	CA_Quantity-Type	

B.6 Package OpticsCalibrationFacility: Radiometry

	Name/role name	Definition	Obligation/ condition	Max. occurrence	Data type/ class	Domain
291.	CA_OpticsFacility Radiometry 6.5.2	information related to the equipment for a radiometric calibration including the laboratory and the in-flight environment	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Optical Sensor)	
292.	radiometricCalibration Date		M	1	dateTime	
293.	CA_Radiometry Laboratory 6.5.3	information regarding the radiometric calibration in a laboratory	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Optics Facility Radiometry)	
294.	calibrationMethod		M	1	CA_Calibration Method	
295.	CA_RadiometryIn-Flight 6.5.4	superclass of the classes CA_RadiometryTestRange and CA_ObjectToObject	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Optics Facility Radiometry)	
296.	lampType	type of illumination used	M	1	Character-String	
297.	atmosphericCondition	state of the atmosphere described with terms such as tropical and midlatitude summer	M	1	Character-String	
298.	aerosolQuantity	notation of visibility of the atmosphere as a part of one hundred	M	1	Real	0,0 to 100,0

	Name/role name	Definition	Obligation/ condition	Max. occurrence	Data type/ class	Domain
299.	CA_RadiometryTest Range 6.5.5	superclass of the class CA_2DReflectanceTarget	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Radiometry nFlight)	
300.	numberPoints	number of targets in the test range	M	1	Integer	≥0
301.	controlPoint	position of the control points	O	N	DirectPosition	
302.	expanse	two-dimensional size of the test field	M	1	Area	≥0
303.	minimumElevation	lowest elevation of the test field	M	1	Length	
304.	maximumElevation	highest elevation of the test field	M	1	Length	
305.	averageElevation	average elevation of the test field	M	1	Length	
306.	CA_2DReflectance Target 6.5.6	information about the two-dimensional reflectance targets	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Radiometry TestRange)	
307.	linearSize	width of a square-shaped or round target	M	1	Length	
308.	targetExpanse	two-dimensional size of the target	M	1	Area	≥0
309.	shape	shape of the target	M	1	CA_Radiometric Target-Shape	
310.	material	material of the target	M	1	CA_Radiometric TargetMaterial	
311.	spectralCharacteristics	spectral characteristics of the target under defined illumination conditions	M	1	CA_Spectrum	
312.	measuredReflectance	reflectance of the target	M	1	CA_Measured Reflectance	
313.	minimumNominal Reflectance	lower end of the range of reflectances of the target	M	1	Real	0,0 to 100,0
314.	maximumNominal Reflectance	upper end of the range of reflectances of the target	M	1	Real	0,0 to 100,0
315.	radiometricStability	description of the radiometric stability of the target	M	1	Character-String	
316.	cleanness	description of the cleanness of the target	M	1	Character-String	
317.	absoluteAccuracy	estimate of the accuracy of the reference value for the reflection	M	1	Real	0,0 to 100,0

	Name/role name	Definition	Obligation/ condition	Max. occurrence	Data type/ class	Domain
318.	CA_ObjectToObject 6.5.7	information for a radiometric calibration based of an object-to-object comparison	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Radiometry InFlight)	
319.	numberImages	number of photos in which the object was photographed and analysed	M	1	Integer	≥0
320.	rmse	root mean square error of the analysis normalized to the full dynamic range of the digital image	M	1	Real	0,0 to 100,0
321.	MI_Instrument 6.5.8	instrument-specific metadata	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (CA_Optics Facility Radiometry)	
322.	citation	complete citation of the instrument	O	N	CI_Citation	
323.	identifier	unique identification of the instrument	M	1	MD_Identifier	
324.	type	name of the type of instrument NOTE Examples are framing, line-scan, pushbroom, pan-frame and whiskbroom.	M	1	CharacterString	
325.	description	textual description of the instrument	O	1	CharacterString	
326.	SD_Sensor 6.5.9	characteristics of the sensor	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (MI_Instrument)	
327.	calibration	information about determination of the relation between instrument readings and physical parameters	O	1	SD_Calibration	
328.	mode	type of observation being made by sensor	O	1	CharacterString	
329.	operationalBand	wavelengths of the electromagnetic spectrum being observed by the sensor	O	N	MI_Band	
330.	CA_Spectrum 6.3.24	data type that defines a spectrum	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	dataType	
331.	numberBands	quantity of spectral bands	M	1	Integer	
332.	wavelength	central wavelength of the respective band	O	N	Length	

	Name/role name	Definition	Obligation/ condition	Max. occurrence	Data type/ class	Domain
333.	response	intensity of the response in a band	O	N	Real	
334.	CA_Measured Reflectance 6.5.13	data type that defines the measured reflectance of a target with respect to a reference	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	dataType	
335.	intensity	measured value of the intensity	M	1	Real	0,0 to 100,0
336.	wavelength	measured value of the wavelength	M	1	Length	
337.	zenithAngle	angle from the zenith towards the measuring instrument	M	1	Angle	0,0 to 90,0
338.	azimuth	horizontal angle to the measuring instrument counted counterclockwise from North	M	1	Angle	0,0 to 360,0
339.	SD_Calibration 6.5.14	circumstances of determination of relation between instrument readings and physical parameters	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	dataType	
340.	calibrationAgency	authority under which calibration took place	M	1	CI_Responsible Party	
341.	calibrationDate	date calibration was carried out	M	1	Date	

B.7 Package OpticsValidation

	Name/role name	Definition	Obligation/ condition	Max. occurrence	Data type/ class	Domain
342.	CA_Geometry Validation 6.6.2	information necessary to perform a validation of the geometric calibration	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Geometry Validation)	
343.	validationMethod	information about the method applied for the validation	M	N	CA_Validation Method	
344.	validationTime	information about the time when the validation was done	M	1	DateTime	
345.	CA_Radiometry Validation 6.6.4	information necessary to perform a validation of the radiometric calibration	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_Geometry Validation)	

	Name/role name	Definition	Obligation/ condition	Max. occurrence	Data type/ class	Domain
346.	rmseComparisonObject	definition of the result of the validation	M	1	Real	0,0 to 100,0
347.	validationTime	information about the time when the validation was done	M	1	DateTime	

B.8 Documentation

	Name/role name	Definition	Obligation/ condition	Max. occurrence	Data type/ class	Domain
348.	CA_Documentation 7.2.2	descriptive information of remote sensing imagery	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Specified Class (MD_Image Description)	
349.	certificateIdentification	information for the identification of the certificate	M	1	MD_Identifier	
350.	dataProductLevel	information about the processing steps that have been applied to a data set	M	1	CA_DataProduct Level	
351.	geometricQuality	information about the geometric quality NOTE The different quality measures are defined in Annex B and in ISO 19157.	M	1	CA_PositionalError	
352.	geometricRadial Resolution	definition of the resolution of imagery along a radius from the image centre	M	1	CA_Geometric Resolution	
353.	geometricTangential Resolution	definition of the resolution of imagery in the tangential direction regarding the image centre	M	1	CA_Geometric Resolution	
354.	radiometricQuality	characterization of the radiometric quality	M	1	DQ_QuantitativeAttributeAccuracy	≥0
355.	stabilizedPlatform	information about the applied stabilized platform	M	1	CharacterString	

B.9 Codelists

	Name	Domain Code	Definition
1.	CA_CalibrationType 6.1.7	caTyCd	type
2.	laboratory	001	calibration performed in a laboratory
3.	testRange	002	calibration performed at a testfield or a test range

	Name	Domain Code	Definition
4.	inSitu	003	calibration performed using targets within or close to the project region
5.	inFlight	002	calibration performed during the flight
6.	vicarious	005	calibration performed using natural targets
7.	cross	006	calibration performed by comparing two or more successive calibrations
8.	other	007	other type of calibration
9.	CA_TargetEnvironment 6.1.8	caTECd	environment
10.	homogeneous	001	target area has no significant variations with regard to the radiometric calibration purpose
11.	inhomogeneous	002	target area has significant variations
12.	other	003	caTECd 1 und 2 do not apply
13.	CA_IrradianceModel 6.1.9	caIM	irradiance
14.	smith_and_gottlieb_1974	001	irradiance model according to Smith and Gottlieb
15.	nickel_labs_1984	002	irradiance model according to Nickel laboratories
16.	wehrli_1985	003	irradiance model according to Wehrli
17.	kurucz_1995	004	irradiance model according to Kurucz 1995
18.	thuillier_1996	005	irradiance model according to Thuillier 1995
19.	thuillier_2001	006	irradiance model according to Thuillier 1996
20.	kurucz_2005	007	irradiance model according to Kurucz 2005
21.	world_radiation_center	008	irradiance model according to the World Radiation Center
22.	solar_diffuser_panel	009	irradiance model according to solar diffuser panel
23.	other	010	irradiance model according to other models
24.	CA_SelfCalibrationModel 6.2.24	caSCCd	model
25.	brown	001	Brown-Conrady model, explained in C.2
26.	fraser	002	Fraser-model, explained in C.3
27.	smac	003	SMAC-model, explained in C.4
28.	ebner	004	Ebner-model, explained in C.5
29.	jacobsen	005	Jacobsen model, explained in C.6
30.	other	006	none of caSCCd does apply
31.	CA_Method 6.3.10	caMeCd	method
32.	darkPixelSubtraction-Method	001	
33.	semiEmpiricalBRDF	002	
34.	radiativeTransferCode	003	
35.	other	004	
36.	CA_SamplingPattern 6.3.23	caSPCd	pattern

	Name	Domain Code	Definition
37.	square	001	sampling of square-shaped ground pixels
38.	rectangular	002	sampling of rectangular-shaped ground pixels
39.	other	003	other shape of the ground pixels
40.	CA_TonalAdjustment 6.3.11	caTACd	adjustment
41.	gammaCorrection	001	tonal adjustment done by a gamma correction
42.	other	002	tonal adjustment done by another method
43.	CA_RadiometricTransfor-mation 6.3.12	caRTCd	transformation
44.	16To8Bit	001	reduction of the dynamic from 16 bit to 8 bit
45.	other	002	other transformation
46.	CA_PointType 6.4.10	caPTCd	point
47.	controlPoint	001	the point is a control point
48.	checkPoint	002	the point is a check point
49.	other	003	the point is of other type
50.	CA_ErrorType 6.3.30	caETCd	error
51.	standardDeviation	001	the error is a standard deviation The standard deviation is defined as $\sigma_{\mathrm{M}} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(Z_i - z_m)^2}$ where σ_{M} is the standard deviation of measured differences; N is the number of observations; Z_i is the ith observable Z; z_m is the mean value of the observable Z (arithmetic mean, $z_m = \frac{1}{N}\sum_{i=1}^{N} Z_i$)
52.	rootMeanSquareError	002	the error is a root mean square error The root mean square error (RMSE) is defined as $\sigma_z = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Z_i - z_t)^2}$ where σ_z is the root mean square error (RMSE); N is the number of observations; Z_i is the ith observable Z; z_{t} is the true value of the observable Z.
53.	other	003	the error is of another type

	Name	Domain Code	Definition
54.	CA_QuantityType 6.4.11	caQTCd	quantity
55.	minimum	001	the positional error is a minimum
56.	maximum	002	the positional error is a maximum
57.	mean	003	the positional error is a mean
58.	other	004	the positional error is of another type
59.	CA_PointSuspension 6.4.12	caPSCd	suspension
60.	cage	001	the point are placed in a calibration cage
61.	tautline	002	the point are placed along taut lines
62.	wall	003	the point are placed at a wall
63.	other	004	the point are placed in another way
64.	CA_InstrumentType 6.4.13	caITCd	type
65.	calibrationCage	001	calibration of the geometry based on a calibration cage
66.	controlPointArray	002	calibration based on a set of control points
67.	goniometer	003	calibration of the geometry based on a goniometer
68.	multicollimator	004	calibration of the geometry based on a multicollimator
69.	wallcorner	005	calibration of the geometry based on wallcorners
70.	other	006	calibration of the geometry based on another method or instrument
71.	CA_GeometricTargetType 6.4.14	caGTCd	type
72.	airforcePattern	001	
73.	coded	002	
74.	coded airforcePattern	003	
75.	siemensStar	004	
76.	swissSpiral	005	
77.	other	006	
78.	CA_CalibrationMethod 6.5.10	caCMCd	method
79.	integratingSphere	001	
80.	flatField	002	
81.	macBethColourTarget	003	
82.	monoChromator	004	
83.	calibratedLightSource	005	
84.	other	006	
85.	CA_RadiometricTarget-Shape 6.5.11	caRTCd	shape
86.	square	001	approximately shape of the radiometric target: square
87.	rectangular	002	approximately shape of the radiometric target: rectangular

	Name	Domain Code	Definition
88.	irregular	003	approximately shape of the radiometric target: irregular
89.	other	004	approximately shape of the radiometric target: other
90.	CA_RadiometricTargetMaterial 6.5.12	caTMCd	material
91.	awning	001	
92.	concrete	002	
93.	gravel	003	
94.	salt	004	
95.	sand	005	
96.	vegetation	006	
97.	other	007	
98.	CA_ValidationMethod 6.6.3	caVMCd	method
99.	testfield	001	validation performed using a testfield
100.	crossStripFlight	002	validation performed using crossing strips or flight lines
101.	secondFlight	003	validation performed using a second photo flight
102.	secondAltitude	004	validation performed using a flight with a second (different) flying height
103.	measurementActualParameters	005	validation performed by a repetition of the measurement of the calibrated parameters
104.	other	006	other validation method
105.	CA_DataProductLevel 7.2.3	caPLCd	level
106.	rawData	001	Unprocessed original data.
107.	level0	002	Reconstructed unprocessed data at full space-time resolution with all available supplemental information to be used in subsequent processing (e.g. ephemeris, health and safety) appended.
108.	level1	003	Reconstructed unprocessed data at full resolution, timereferenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and geo-referencing parameters (e.g. ephemeris), computed and appended but not applied to the L0 data. Radiometrically corrected and calibrated data in physical units at full instrument resolution as acquired.
109.	level2	004	Derived geophysical parameters (e.g. sea surface temperature and surface reflectance) at the same resolution and location as L1 source data.
110.	level3	005	Data or retrieved geophysical parameters (e.g. leaf area index) which have been spatially and/or temporally re-sampled (i.e. derived from L1 or L2 products), usually with some completeness and consistency. Such re-sampling may include averaging and compositing.
111.	level4	006	Model output or results from analysis of lower level data (i.e. parameters that are not directly measured by the instruments, but are derived from these measurements).
112.	other	007	other classification level

Annex C
(normative)

Self calibration models

C.1 General

Annex C provides a list of the standardized self-calibration models. This list comprises of the following models:

- Brown-Conrady model or Brown model
- Fraser model
- SMAC model
- Ebner model
- Jacobsen model

C.2 Brown-Conrady model

The first publication about systematic image errors came from Reference [18]. Based on this, the first set of additional parameters for self-calibration was published in 1971.[19]

The Brown-Conrady model is mostly just named Brown model and corresponds to:

$$\Delta x = K_1 * (r^2 - R_0^2) * x + K_2 * (r^4 - R_0^4) * x + K_3 * (r^6 - R_0^6) * x + T_1 * (r^2 + 2x^2) + 2 * T_2 * x * y - A_1 * x + A_2 * y \quad \text{(C.1)}$$

$$\Delta y = K_1 * (r^2 - R_0^2) * y + K_2 * (r^4 - R_0^4) * y + K_3 * (r^6 - R_0^6) * y + 2 * T_1 * x * y + T_2 * (r^2 + 2y^2) + A_1 * y \quad \text{(C.2)}$$

where

r	is the radial distance from principal point (origin of image coordinates x and y);
K_1, K_2, K_3	are the radial symmetric distortions corresponding to r^3, r^5 respectively r^7;
R_0	is a constant value (radial distance of zero crossing of the distortion function) to eliminate or reduce the correlation of the radial symmetric distortion with the focal length;
T_1 and T_2	describe the tangential distortion:

- A_1 describes affinity;
- A_2 describes angular affinity.

The factors K_1 up to K_3 of the radial symmetric distortion are strongly correlated, because of this mostly K_3 is not used.

The additional parameters of the Brown-Conrady model are: K_1, K_2, K_3, T_1, T_2, A_1 and A_2 – in total 7 additional parameters. It does not include a correction of the focal length and the principal point.

C.3 Fraser model

The Fraser model extends the Brown-Conrady model by the interior orientation:[20][21]

$$\Delta x = -x_0 - \frac{\bar{x}}{c}\Delta c + \bar{x}r^2K_1 + \bar{x}r^4K_2 + \bar{x}r^6K_3 + (2\bar{x}^2 + r^2)T_1 + 2T_2\overline{xy} + F_1\bar{x} + F_2\bar{y} + \Delta x_u \qquad \text{(C.3)}$$

$$\Delta y = -y_0 - \frac{\bar{y}}{c}\Delta c + \bar{y}r^2K_1 + \bar{y}r^4K_2 + \bar{y}r^6K_3 + 2T_1\overline{xy} + (2\bar{y}^2 + r^2)T_2 + \Delta y_u \qquad \text{(C.4)}$$

where

Δc corresponds to a correction of the focal length;

x_0 corresponds to a shift of the principal point in x-direction;

y_0 corresponds to a shift of the principal point in y-direction;

F_1 corresponds to affinity;

F_2 corresponds to angular affinity.

The coefficients F_1 and F_2 have the same function as A_1 and A_2 in the Brown-Conrady model. In the Brown-Conrady model the affinity A_1 is equally distributed to x and y, while in the above model from Fraser it is only influencing the x-image coordinate, causing a correlation to the focal length. The interior orientation (focal length and location of principal point) only can be determined with control points having a depth variety in view direction.

C.4 SMAC model

SMAC stands for Simultaneous Multiframe Analytical Calibration. In the SMAC model, the radial distortion is expressed as (δx, δy).[22]

$$\delta x = (x - x_p)\,(K_o + K_1r^2 + K_2r^4 + K_3r^6 \ldots.) \qquad \text{(C.5)}$$

$$\delta y = (y - y_p)\,(K_o + K_1r^2 + K_2r^4 + K_3r^6 \ldots.) \qquad \text{(C.6)}$$

where

x_p, y_p are the photo coordinates of the principal point with $r^2 = (x - x_p)^2 + (y - y_p)^2$;

K is the coefficient(s) representing radial, symmetrical distortion.

The distortion due to decentering of the compound objective is expressed as: (Δx, Δy)

$$\Delta x = (1 + P_3r^2)\,(P_1\,(r^2 + 2\,x^2) + 2\,P_2x\,y) \qquad \text{(C.7)}$$

$$\Delta y = (1+ P_3 r^2)\ (2\ P_1 x\, y + P_2 (r^2 + 2\ y^2)) \quad \text{(C.8)}$$

where P coefficients represent decentering distortion.

The corrected photo coordinates are then:

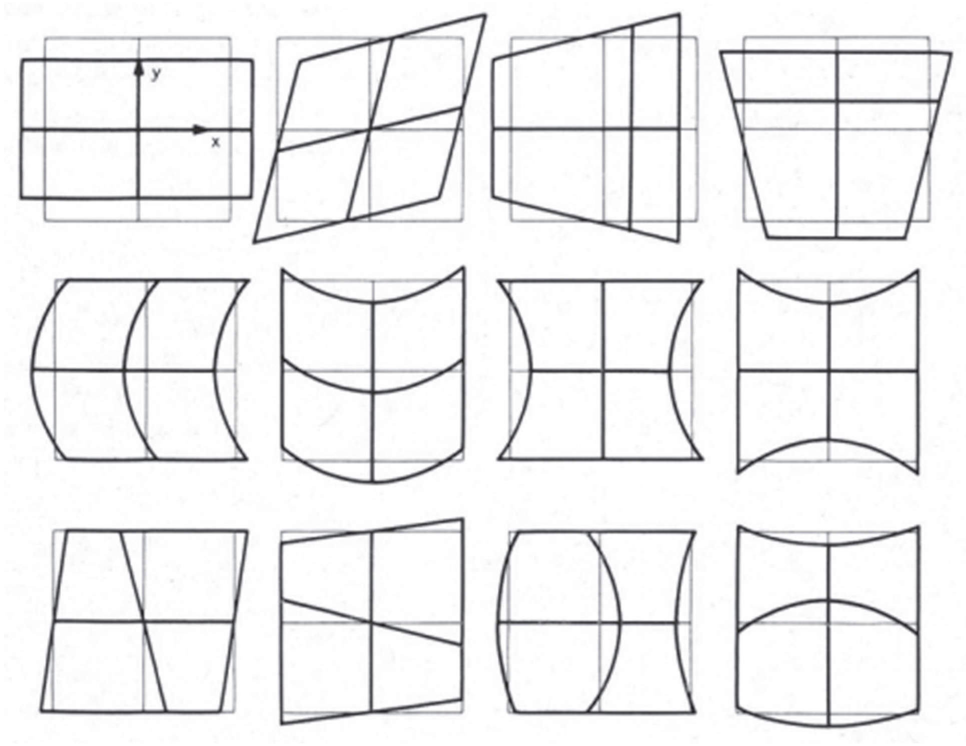
$$x_c = x + \delta x + \Delta x \quad \text{(C.9)}$$

$$y_c = y + \delta y + \Delta y \quad \text{(C.10)}$$

This corresponds to the Brown-Conrady model without affinity and angular affinity.

C.5 Ebner model

The Ebner model uses a totally different solution for the additional parameters. It is a set of parameters, eliminating the systematic image errors in the 9 Gruber points (raster of 3 × 3 points with the centre point in the image centre and the other in a grid with a spacing of 0.4 * image format in x-direction shown as b in Figure C.1).[23]



$$\Delta x = +e_1 x \quad +e_2 y \quad -e_3\left(2x^2 - 4b^2/3\right) \quad +e_4 xy$$
$$+e_5\left(y^2 - 2b^2/3\right) \quad +e_7 x\left(y^2 - 2b^2/3\right)$$
$$+e_9\left(x^2 - 2b^2/3\right)y \quad +e_{11}\left(x^2 - 2b^2/3\right)\left(y^2 - 2b^2/3\right)$$

$$\Delta y = -e_1 y \quad +e_2 x \quad +e_3 xy \quad -e_4\left(2y^2 - 4b^2/3\right)$$
$$+e_6\left(x^2 - 2b^2/3\right) \quad +e_8\left(x^2 - 2b^2/3\right)y$$
$$+e_{10} x\left(y^2 - 2b^2/3\right) \quad +e_{12}\left(x^2 - 2b^2/3\right)\left(y^2 - 2b^2/3\right)$$

NOTE The geometric influence of the Ebner-parameters can be characterized as follows. The positions of the summands refer to the position of the diagrams.

Figure C.1 — Graphic representation of the effect of the 12 Ebner-parameters

The 12 additional parameters of the Ebner model respect that some of the unknowns, required for a grid of 3 * 3 points, are compensated by the exterior orientation. The Ebner model is based on a square size of the images; it is only a mathematical model of compensation without physical background. It cannot express the radial distortion directly.

C.6 Jacobsen model

The Jacobsen model is basically a physical model, which is supplemented by some mathematical terms to be able to compensate some effects which cannot be compensated by the Brown-Conrady model. Instead of the highly correlated radial symmetric terms K_2 and K_3 the additional parameters j_{10} and j_{11} are used, which show very low correlations. Only for close range cameras with few optical components and strong radial symmetric distortion the parameter K_2 may have some advantages why it is included in program system BLUH as parameter j_{27}.[24]

Table C.1 — General additional parameters of Jacobsen model

x, y = image coordinates normalized to maximal radial distance 162,6 mm (scale factor: 162,6/maximal radial distance) $r^2 = x^2 + y^2$ b = arctan (y/x)			
1.	$x' = x - y \cdot j_1$	$y' = y - x \cdot j_1$	angular affinity
2.	$x' = x - x \cdot j_2$	$y' = y + y \cdot j_2$	affinity
3.	$x' = x - x \cdot \cos 2b \cdot j_3$	$y' = y - y \cdot \cos 2b \cdot j_3$	
4.	$x' = x - x \cdot \sin 2b \cdot j_4$	$y' = y - y \cdot \sin 2b \cdot j_4$	
5.	$x' = x - x \cdot \cos b \cdot j_5$	$y' = y - y \cdot \cos b \cdot j_5$	
6.	$x' = x - x \cdot \sin b \cdot j_6$	$y' = y - y \cdot \sin b \cdot j_6$	
7.	$x' = x + y \cdot r \cdot \cos b \cdot j_7$	$y' = y - x \cdot r \cdot \cos b \cdot j_7$	tangential distortion 1
8.	$x' = x + y \cdot r \cdot \sin b \cdot j_8$	$y' = y - x \cdot r \cdot \sin b \cdot j_8$	tangential distortion 2
9.	$x' = x - x \cdot (r^2\text{-}16384) \cdot j_9$	$y' = y - y \cdot (r^2 - 16384) \cdot j_9$	radial symmetric r^3
10.	$x' = x - x \cdot \sin(r \cdot 0{,}049\ 087) \cdot j_{10}$	$y' = y - y \cdot \sin(r \cdot 0.049\ 087) \cdot j_{10}$	radial symmetric
11.	$x' = x - x \cdot \sin(r \cdot 0{,}098\ 174) \cdot j_{11}$	$y' = y - y * \sin(r \cdot 0\ 0{,}098\ 174) \cdot j_{11}$	radial symmetric
12.	$x' = x - x \cdot \sin 4b \cdot j_{12}$	$y' = y - y \cdot \sin 4b \cdot j_{12}$	

For aerial images usually the interior orientation cannot be determined, but if three-dimensional distributed ground control points are available, the corresponding parameters are included as $j_{13} - j_{15}$:

Table C.2 — Additional parameters of Jacobsen model for the aerial case

13.	$x' = x + x \cdot j_{13}$	$y' = y + y \cdot j_{13}$	focal length
14.	$x' = x + j_{14}$	$y' = y$	principal point x
15.	$x' = x$	$y' = y + j_{15}$	principal point y

The parameters $j_{42} - j_{88}$ of the Jacobsen model are not normative.

BLUH includes also camera-specific additional parameters for the UltraCam and the DMC (I).

Parameters $j_{42} - j_{73}$ are camera-specific parameters for the UltraCam.

UltraCam subimages:			
	7	8	1
	6		2
	5	4	3

BSXU = 11,25 mm	BSYU = 17,25 mm	for vertical UltraCam format
BSXU = 17,25 mm	BSYU = 11,25 mm	for horizontal UltraCam format

Table C.3 — Scale parameters for UltraCam

42.	$x' = x - \mathrm{BSXU} \cdot j_{42}$	$y' = y - \mathrm{BSYU} \cdot j_{42}$	UltraCam sub area 1
43.	$x' = x - \mathrm{BSXU} \cdot j_{43}$	$y' = y$	UltraCam sub area 2
44.	$x' = x - \mathrm{BSXU} \cdot j_{44}$	$y' = y + \mathrm{BSYU} \cdot j_{44}$	UltraCam sub area 3
45.	$x' = x$	$y' = y + \mathrm{BSYU} \cdot j_{45}$	UltraCam sub area 4
46.	$x' = x + \mathrm{BSXU} \cdot j_{46}$	$y' = y + \mathrm{BSYU} \cdot j_{46}$	UltraCam sub area 5
47.	$x' = x + \mathrm{BSXU} \cdot j_{47}$	$y' = y$	UltraCam sub area 6
48.	$x' = x + \mathrm{BSXU} \cdot j_{48}$	$y' = y - \mathrm{BSYU} \cdot j_{48}$	UltraCam sub area 7
49.	$x' = x$	$y' = y - \mathrm{BSYU} \cdot j_{49}$	UltraCam sub area 8

Table C.4 — Shift X parameters for UltraCam

50.	$x' = x - j_{50}$	$y' = y$	UltraCam sub area 1
51.	$x' = x - j_{51}$	$y' = y$	UltraCam sub area 2
52.	$x' = x - j_{52}$	$y' = y$	UltraCam sub area 3
53.	$x' = x - j_{53}$	$y' = y$	UltraCam sub area 4
54.	$x' = x - j_{54}$	$y' = y$	UltraCam sub area 5
55.	$x' = x - j_{55}$	$y' = y$	UltraCam sub area 6
56.	$x' = x - j_{56}$	$y' = y$	UltraCam sub area 7
57.	$x' = x - j_{57}$	$y' = y$	UltraCam sub area 8

Table C.5 — Shift Y parameters for UltraCam

58.	$x' = x$	$y' = y - j_{58}$	UltraCam sub area 1
59.	$x' = x$	$y' = y - j_{59}$	UltraCam sub area 2
60.	$x' = x$	$y' = y - j_{60}$	UltraCam sub area 3
61.	$x' = x$	$y' = y - j_{61}$	UltraCam sub area 4
62.	$x' = x$	$y' = y - j_{62}$	UltraCam sub area 5
63.	$x' = x$	$y' = y - j_{63}$	UltraCam sub area 6
64.	$x' = x$	$y' = y - j_{64}$	UltraCam sub area 7
65.	$x' = x$	$y' = y - j_{65}$	UltraCam sub area 8

Table C.6 — Rotation parameters for UltraCam

66.	$x' = x - (y - \mathrm{BSYU}) \cdot j_{66}$	$y' = y + (x - \mathrm{BSXU}) \cdot j_{66}$	UltraCam sub area 1
67.	$x' = x - y \cdot j_{67}$	$y' = y + (x - \mathrm{BSXU}) \cdot j_{67}$	UltraCam sub area 2
68.	$x' = x - (y + \mathrm{BSYU}) \cdot j_{68}$	$y' = y + (x - \mathrm{BSXU}) \cdot j_{68}$	UltraCam sub area 3
69.	$x' = x - (y + \mathrm{BSYU}) \cdot j_{69}$	$y' = y + x \cdot j_{69}$	UltraCam sub area 4
70.	$x' = x - (y + \mathrm{BSYU}) \cdot j_{70}$	$y' = y + (x + \mathrm{BSXU}) \cdot j_{70}$	UltraCam sub area 5
71.	$x' = x - y \cdot j_{71}$	$y' = y + (x + \mathrm{BSXU}) \cdot j_{71}$	UltraCam sub area 6
72.	$x' = x - (y - \mathrm{BSYU}) \cdot j_{72}$	$y' = y + (x - \mathrm{BSXU}) \cdot j_{72}$	UltraCam sub area 7
73.	$x' = x - (y - \mathrm{BSYU}) \cdot j_{73}$	$y' = y + x \cdot j_{73}$	UltraCam sub area 8

j_{74} – j_{77} distortion of DMC subcameras (view direction x = 10,06°, view direction y = 17,66°).

WX=atan(x/120) WY=atan(y/120) $WR=\sqrt{WX^2+WY^2}$ $RO=\sqrt{x^2+y^2}$

for x>0 and y<0: WTX=WX-0,175 58 WTY=WY+0,308 23

for x>0 and y>0: WTX=WX-0,175 58 WTY=WY-0,308 23

for x<0 and y>0: WTX=WX+0,175 58 WTY=WY-0,308 23

for x<0 and y<0: WTX=WX-0,175 58 WTY=WY+0,308 23

$$RSING=\sqrt{(120\times\tan(WTX))^2+(120\times\tan(WTY))^2}$$

$FACR$=($RSING^2$-1850)*1,0E-7

$FACRX$=$FACR$•120 • tan(WTX)

$FACRY$=$FACR$•120 • tan(WTY)

$FACRS$=($FACRX$ • x/RO + $FACRY$ • y/RO) /[cos(WR)*cos(WR)]

$FACTS$=-($FACRX$ • y/RO + $FACRY$ • x/RO) /cos(WR)

Table C.7 — Distortion of the DMC-subcameras

74	$x' = x$ - $FACRS$• x/RO - $FACTS$• y/RO • j_{74}	$y' = y$ - $FACRS$• y/RO + $FACTS$• x/RO• j_{74}	DMC subcamera 1 for x > 0. and y < 0
75	$x' = x$ - $FACRS$• x/RO - $FACTS$• y/RO • j_{75}	$y' = y$ - $FACRS$• y/RO + $FACTS$• x/RO• j_{75}	DMC subcamera 2 for x > 0. and y > 0
76	$x' = x$ - $FACRS$• x/RO - $FACTS$• y/RO • j_{76}	$y' = y$ - $FACRS$• y/RO + $FACTS$• x/RO• j_{76}	DMC subcamera 3 for x < 0. and y > 0
77	$x' = x$ - $FACRS$• x/RO - $FACTS$• y/RO • j_{77}	$y' = y$ - $FACRS$• y/RO + $FACTS$• x/RO• j_{77}	DMC subcamera 4 for x < 0. and y < 0

Table C.8 — Common parameters of the DMC-subcameras

79.	$x' = x - x$•|y| •0.000188• j_{79}	$y' = y$ – (|x|•y^3•0.000000015+y^3•0.0000012) • j_{79}	
80.	$x' = x$ - $FACRS$• x/RO - $FACTS$• y/RO • j_{80}	$y' = y$ - $FACRS$• y/RO + $FACTS$• x/RO• j_{80}	

Parameter j_{79} is the common change of focal length of DMC-subcameras.

Parameter j_{80} has the same formula as j_{74} – j_{77}, but one value for all subcameras parameter j_{80} should not be used together with parameters j_{74} – j_{77}.

It has been shown, that for the DMC (I) the additional parameters j_{79} and j_{80} are satisfying as camera-specific parameters, while for the UltraCam the additional parameters j_{42} – j_{73} may be required. Parameter j_{79} corresponds to the same radial symmetric distortion of all 4 panchromatic subcameras, projected to the virtual image plane, while parameter j_{80} corresponds to the same change of the focal length for all 4 subcameras (butterfly-shape).

During the camera test of the German Society of Photogrammetry, Remote Sensing and Geoinformation it has been shown, that digital mid-format cameras have geometric effects which could not be compensated by all the used bundle block adjustment programs using different sets of additional parameters. Because of this some special additional parameters have been added to the program system BLUH:

Table C.9 — Compensation of corner effects of digital mid-format cameras

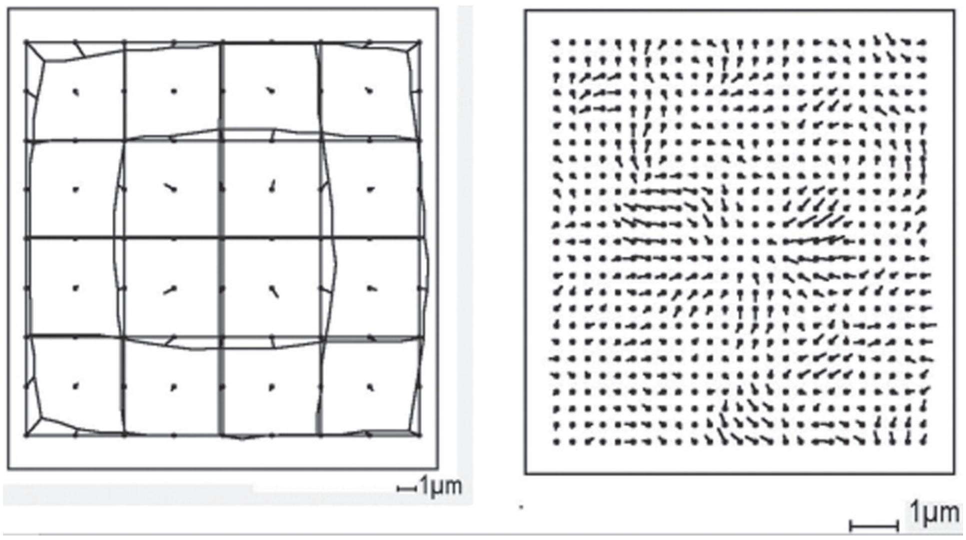
81.	$x' = x + j_{81}*ABS(x^3 * y^3) * 10–9$	$y' = y - j_{81}*ABS(x^3 * y^3) * 10–9$	for lower right quarter
82.	$x' = x + j_{82}*ABS(x^3 * y^3) * 10–9$	$y' = y + j_{82}*ABS(x^3 * y^3) * 10–9$	for lower left quarter
83.	$x' = x + j_{83}*ABS(x^3 * y^3) * 10–9$	$y' = y - j_{83}*ABS(x^3 * y^3) * 10–9$	for upper left quarter
84.	$x' = x + j_{84}*ABS(x^3 * y^3) * 10–9$	$y' = y + j_{84}*ABS(x^3 * y^3) * 10–9$	for upper right quarter
85.	$x' = x + j_{85}*x^2 * y^2 * 10–6$	$y' = y + j_{85}*x2 * y^2 * 10–6$	for lower right quarter
86.	$x' = x + j_{86}*x^2 * y^2 * 10–6$	$y' = y + j_{86}*x2 * y^2 * 10–6$	for lower left quarter
87.	$x' = x + j_{87}*x^2 * y^2 * 10–6$	$y' = y + j_{87}*x2 * y^2 * 10–6$	for upper left quarter
88.	$x' = x + j_{88}*x^2 * y^2 * 10–6$	$y' = y + j_{88}*x2 * y^2 * 10–6$	for upper right quarter

Based on the experience with a larger number of digital cameras, now the parameters j_1 to j_{12} and j_{81} to j_{88} are used as default parameters in the Jacobsen model, if the interior orientation (parameters $j_{13} – j_{15}$) shall not be included.

In the program system BLUH the significance of the additional parameters is checked and the not required parameters are excluded automatically. This function has a meaning for smaller data sets, but for a camera calibration based on a high number of image points and several images, it is not important.

Another method for camera calibration is based on a bundle block adjustment without self-calibration. One of the results of such a bundle block adjustment is the residuals (remaining image coordinate errors). The residuals of all used images can be overlaid corresponding to their image positions and averaged in small subareas. By averaging the random error components are reduced and the systematic parts are remaining. It may be required to use a local average filter to reduce remaining random parts in subareas with a limited number of points. This procedure operates without any pre-assumption and is able to deliver good results if enough images and image points are available.

Dimensions in micrometres



Key

left-hand side systematic image errors based on additional parameters $j_1 – j_{12}$

right-hand side averaged residuals of block adjustment without self-calibration

Figure C.2 — Small residual errors after the application of the Jacobsen parameters

The averaged residuals will not be identical to the systematic image errors because of remaining correlation to the exterior orientation. But if the averaged residuals are used for a pre-correction of the image coordinates, the following bundle block adjustment without self-calibration will lead nearly to the same object coordinates as the bundle block adjustment with the original image coordinates with self-calibration. The root mean square differences of the object points are in the range of 20 % up to 30 % of the absolute accuracy determined by independent check points.

Annex D
(informative)

Calibration and validation quality measures

D.1 General

Annex D provides a list of standardized calibration and validation quality measures in D.2.

D.2 List of calibration and validation (CA) quality measures

The quality measures for the calibration and validation quality elements are provided in Tables D.1 to D.3.

Table D.1 — Integral Stray-light of an image-forming system

Line	Item	Description
1	Name	Integral Stray-light of an image-forming system
2	Alias	Stray-light Ghosts Narcissus False light
3	CA quality element	–
4	CA quality basic measure	–
5	Definition	Integral stray-light is defined as the combined / superimposed light intensity caused by reflection of internal surfaces and mountings, by ghost imaging, narcissus effects and false light. Integral stray-light intensity is not generated directly from the detected object, but from its interaction with the image-forming system. Integral stray-light shall be understood as added and locally different signal offset which does not contain object information, but could modify the image in unknown way. Integral stray-light is given here as maximum possible signal offset in per cent (%) due to instrument features. The value allows the clear separation between object and instrument features in later images.
6	Description	–
7	Parameter	–
8	CA quality value type	–
9	CA quality value structure	–
10	Source reference	–
11	Example of image-forming systems	Charge Coupled Device (CCD) camera Imaging spectrometer
12	Identifier	1

Table D.1 *(continued)*

Line	Item	Description
13	Measurement Set-up	Integrated sphere (able for dim) with totally black (light trap) cone adjusted within the output port plane (or inside) of the sphere. Cone positioning at different locations over the output port plane of the sphere would be helpful. Cone diameter shall be greater than generated image blurring of the instrument due to close-up view of the cone. Pay attention to close to really black cone surface and geometry (light trap). Perfect black-out of the lab.
14	Software	–
15	Measurement Procedure	Adjust the image-forming instrument (including baffle) as closest as possible to the output port of the integrated sphere. Adjust the illumination level close to 80 % of full well capacity of the image-forming instrument (or above if linear internal radiometric calibration of the sphere is available). Take images while the image-forming instrument is flat-field illuminated both, with and without cone in the optical path. (Use longest exposure time of the instrument if linearity is confirmed and anti-blooming works perfectly in order to detect the lowest signal within the cone centre image). Repeat for different cone positions. Perform dark signal and DSNU and PRNU correction before data evaluation. The signal ratio of the response of the dark CCD pixels (close to the centre of the cone) and the bright CCD pixels (away from the cone) result in the maximum integral stray-light value. NOTE The approach does not give the chance to separate single sources of stray-light and also does not give the chance to correct the measurement set-up influence from the result. Maybe the real value of the instrument is somewhat lower than generated here, but never will be higher.
16	Result	Maximum possible integral stray-light in per cent (%)
17	Accuracy	Strongly dependent on set-up design features

Table D.2 — Modulation Transfer Function of a CCD as subsystem

Line	Item	Description
1	Name	Modulation Transfer Function of a CCD as subsystem
2	Alias	MTF Modulus of the Optical Transfer Function (OTF) Modulus of the Fourier transformed Point Spread Function (PSF) Geometric resolution Sinusoidal frequency response
3	CA quality element	–
4	CA quality basic measure	–
5	Definition	The MTF defines the imaging resolution power of an image-forming system or subsystem or component. The MTF is given as the ratio of output sinusoidal contrast response of the system to input sinusoidal contrast versus different spatial frequencies. It is normalized to zero spatial frequency and covers values between 1 for maximum contrast and 0 without contrast. The MTF is out of unit and often presented as a curve: MTF versus spatial frequency in line pairs per mm (lp/mm). The shape of the MTF curve of an image-forming system is strongly determined by focus status, wavelength, optical path and detector features.
6	Description	–
7	Parameter	–
8	CA quality value type	–
9	CA quality value structure	–
10	Source reference	–
11	Example of CCD as subsystem	Single CCD, equipped with readout electronics Complete focal plane
12	Identifier	2

Table D.2 — *(continued)*

Line	Item	Description
13a	Measurement Set-up I	Adjustment of an auxiliary test optics with certificated stand-alone MTF knowledge (on axis) in front of CCD to create an interim CCD camera. Collimator at infinity able for test target assembly in its focus. Test targets (pinhole, bar codes, slit, knife edge) exchangeable in the focus of the collimator. Precise stepping motors in two-dim. in collimator focus for sampling procedure. Interim CCD camera fixed mounted and facing the collimator. Illumination by Tungsten halogen lamp combined with monochromator or metal interference filters, resp. within the VIS /NIR spectral range.
13b	Measurement Set-up II	Imaging of a test chart (in reflection or transmission) on a couple of CCD pixels. Usage of a test optics which assigns the slanted edge from test chart to CCD pixels with a selected scale. Test optics is required to be distortion-free, apo-chromatic and with certificated stand-alone MTF knowledge for correction. Usage of precise stages to adjust test chart, auxiliary test lens and CCD relatively to each other in focus. Tungsten halogen lamp combined with monochromator or MIF needed for illumination.
14	Software	Set-up control software able for running batches.
15a	Measurement Procedure: “Single pixel illumination” using set-up I	Imaging of a pinhole spot onto nearly one CCD pixel. Subpixel sampling by the pinhole spot in 2 dimensions with step width according to the sampling theorem over at least ±5 pixels (to be examined by application of the sampling theorem) . As result: signal of one pixel as function of two-dim. sampling steps. Two-dim. Fourier transformation of the two-dim. sampled signal vs. steps. Correction from spot size and collimator and auxiliary test optics in frequency domain.
15b	Measurement Procedure: “Bar code illumination” using set-up I	Imaging of appropriate simple bar code or sinusoidal bar code spots onto CCD pixels. Arrange maximum contrast by phase shifting. Flat-field correction over the used CCD pixel range. Change the spatial frequency of the bar codes. Rotate the azimuth of the bar code spot on CCD at identical position. In case of simple bar coding use odd harmonics additionally for MTF generation from contrast transfer function (CTF). Correction of auxiliary test optics MTF. Evaluation of the imaging contrast as function of frequency, azimuth, wavelength, optical path …

Table D.2 *(continued)*

Line	Item	Description
15c	Measurement Procedure: “Knife edge measurement” using set-up I	Imaging of a knife edge onto a couple of CCD pixels. Arrange azimuth with respect to CCD orientation. Flat-field correction of the used CCD pixel range. Perform Fourier Transformation of the signal. Correction of auxiliary test optics MTF.
15d	Measurement Procedure: “Slanted edge measurement” using set-up II	See ISO 12233.
16	Result	Subsystem CCD MTF vs. spatial frequency as function of wavelength range, CCD features and corrected from measurement set-up influences.
17	Accuracy	Better than ± 10 % with respect of the MTF value at Nyquist frequency.

Table D.3 — Modulation Transfer Function of an image-forming system

Line	Item	Description
1	Name	Modulation Transfer Function of an image-forming system.
2	Alias	MTF Modulus of the Optical Transfer Function (OTF) Modulus of the Fourier transformed Point Spread Function (PSF) Geometric resolution Sinusoidal frequency response
3	CA quality element	–
4	CA quality basic measure	–
5	Definition	The MTF defines the imaging resolution power of an image-forming system or subsystem or component. The MTF is given as the ratio of output sinusoidal contrast response of the system to input sinusoidal contrast versus different spatial frequencies. It is normalized to zero spatial frequency and covers values between 1 for maximum contrast and 0 without contrast. The MTF is out of unit and often presented as a curve: MTF versus spatial frequency in line pairs per mm (lp/mm). The shape of the MTF curve of an image-forming system is strongly determined by focus status, wavelength, optical path and detector features.
6	Description	–
7	Parameter	–
8	CA quality value type	–
9	CA quality value structure	–
10	Source reference	–
11	Example of image-forming systems	CCD camera Imaging spectrometer
12	Identifier	3

Table D.3 *(continued)*

Line	Item	Description
13	Measurement Set-up	Collimator at infinity able for test target assembly in its focus. Test targets (pinhole, bar codes, slit, knife edge) exchangeable in the focus of the collimator. Precise stepping motors in two-dim. in collimator focus for sampling procedure. Image-forming system fixed mounted or positioned on a gimbal mount facing the collimator. Illumination by Tungsten halogen lamp combined with monochromator or metal interference filters, resp. within the VIS /NIR spectral range.
14	Software	Set-up control software able for running batches .
15a	Measurement Procedure: “Single pixel illumination”	Imaging of a pinhole spot onto nearly one CCD pixel. Subpixel sampling by the pinhole spot in 2 dimensions with step width according to the sampling theorem over at least ±5 pixels (to be examined by application of the sampling theorem). As result: signal of one pixel as function of two-dim. sampling steps. Two-dim. Fourier transformation of the two-dim. sampled signal vs. steps. Correction from spot size and collimator in frequency domain.
15b	Measurement Procedure: “Bar code illumination”	Imaging of appropriate simple bar code or sinusoidal bar code spots onto CCD pixels. Arrange maximum contrast by phase shifting. Flat-field correction over the used CCD pixel range. Change the spatial frequency of the bar codes. Rotate the azimuth of the bar code spot on CCD at identical position. In case of simple bar coding use odd harmonics additionally for MTF generation from contrast transfer function (CTF). Evaluation of the imaging contrast as function of frequency, azimuth, wavelength and optical path.
15c	Measurement Procedure: “Knife edge measurement”	Imaging of a knife edge onto a couple of CCD pixels. Arrange azimuth with respect to CCD orientation. Flat-field correction of the used CCD pixel range. Perform Fourier Transformation of the signal.
16	Result	MTF vs. spatial frequency as function of wavelength range, optical path, CCD features and corrected from measurement set-up influences.
17	Accuracy	Better than ±10 % with respect of the MTF value at Nyquist frequency.

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