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

**Part 1:
Optical sensors**

*Information géographique — Calibration et validation de capteurs de
télédétection —*

Partie 1: Capteurs optiques



Reference number
ISO/TS 19159-1:2014(E)

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Published in Switzerland

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2. www.iso.org/directives

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

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/m²).

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 wavelength 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 $dY(\lambda)$ by the monochromatic detector input $dX_e(\lambda) = X_{e,\lambda}(\lambda) \cdot d\lambda$ in the wavelength interval $d\lambda$ 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.

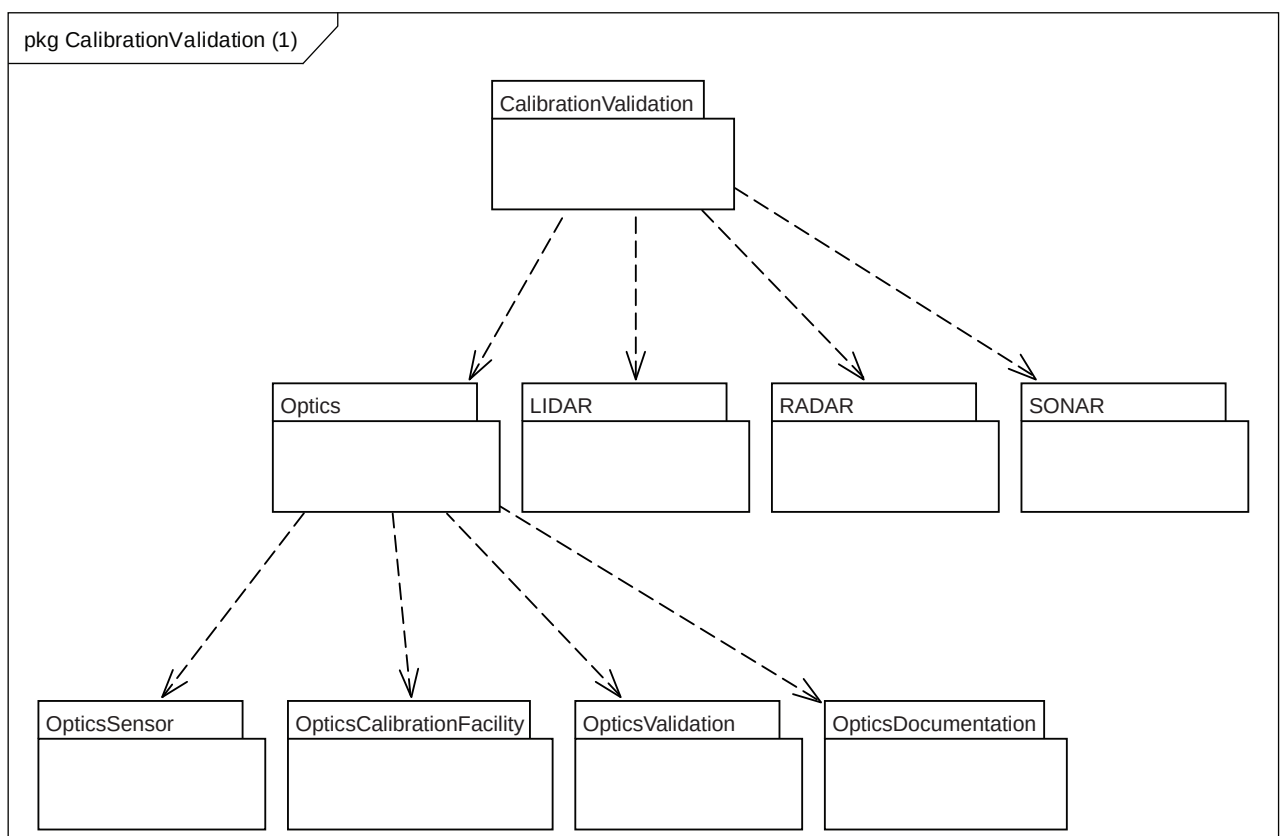


Figure 1 — Package diagram of the package CalibrationValidation

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).

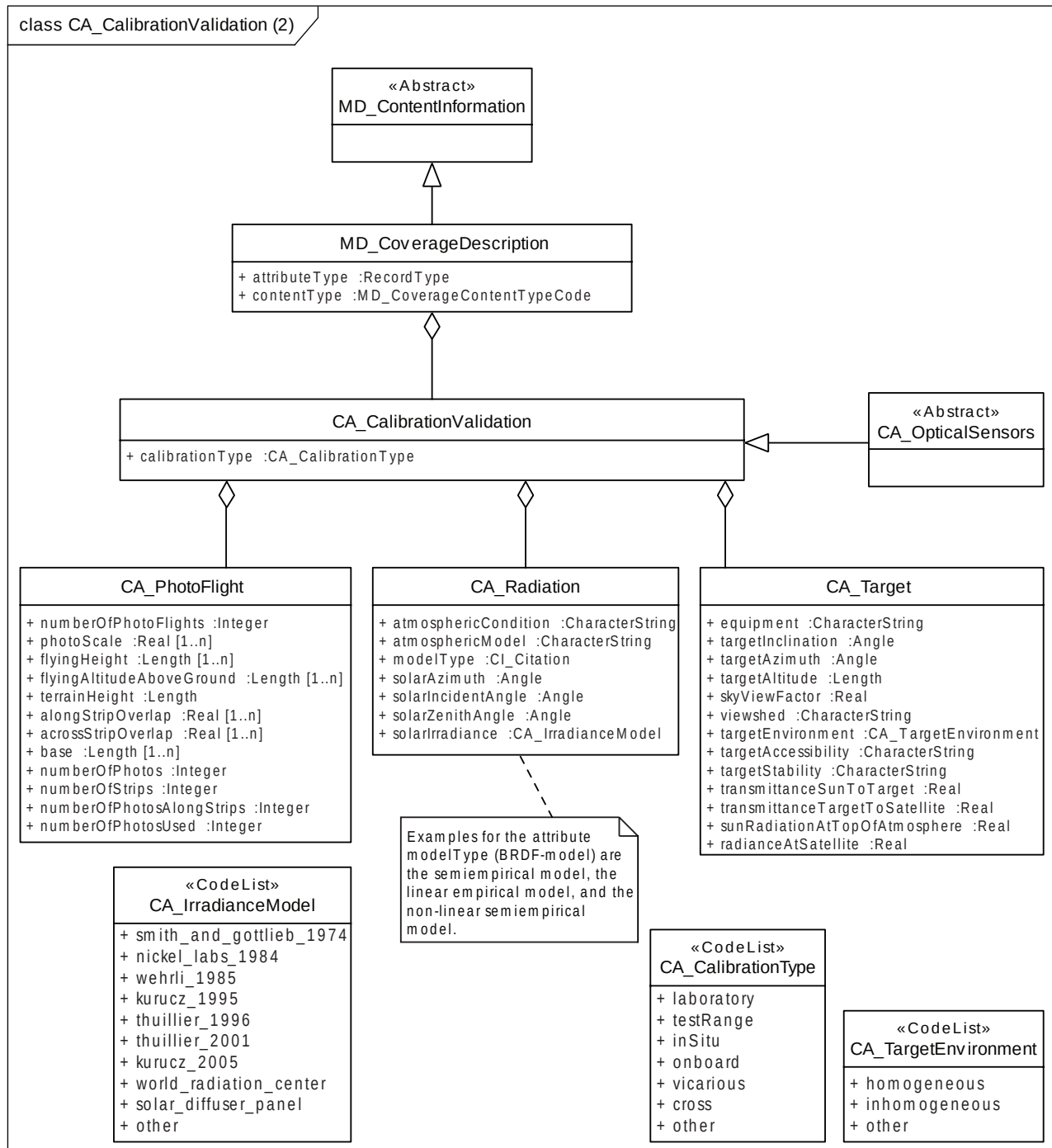


Figure 2 — Top-level class diagram of ISO 19159 (all parts)

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](#).

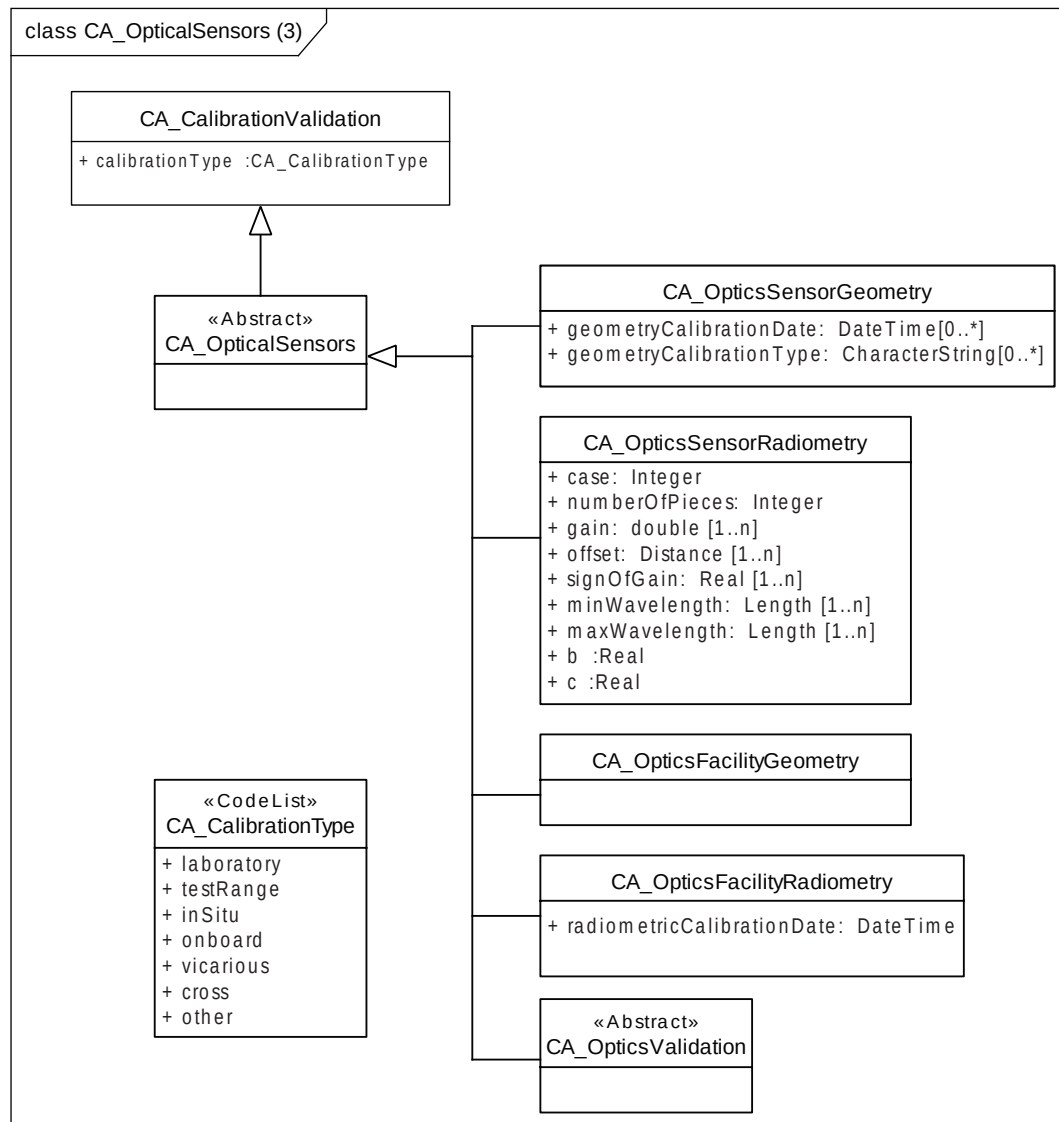


Figure 3 — Class diagram of CA_OpticalSensors and its subordinate classes

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

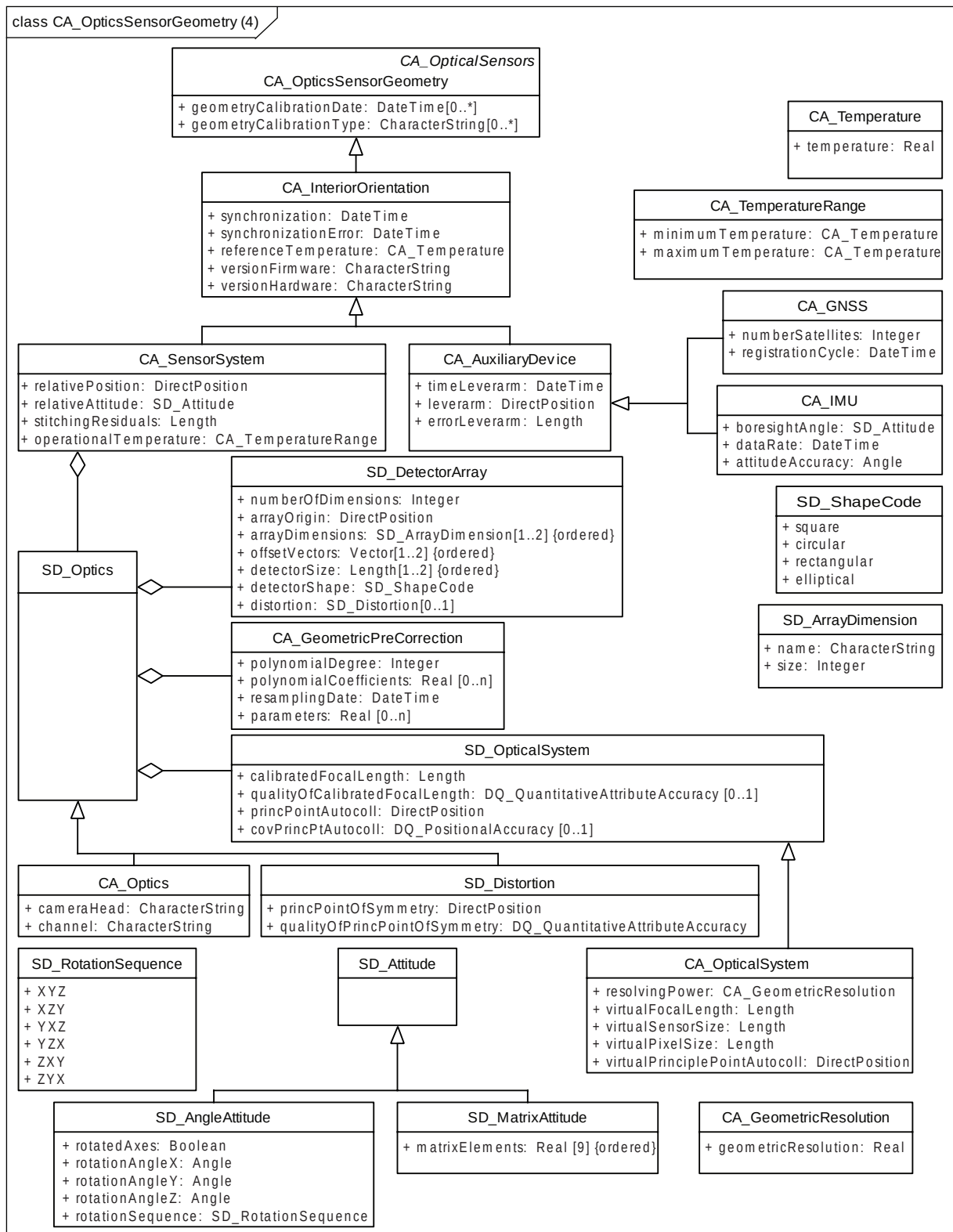
6.2.1 General

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 or 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 attribute `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

$$\begin{aligned}
 r_{11} &= \cos\varphi * \cos\kappa \\
 r_{12} &= -\cos\varphi * \sin\kappa \\
 r_{13} &= \sin\varphi \\
 r_{21} &= \cos\omega * \sin\kappa + \sin\omega * \sin\varphi * \cos\kappa \\
 r_{22} &= \cos\omega * \cos\kappa - \sin\omega * \sin\varphi * \sin\kappa \\
 r_{23} &= -\sin\omega * \cos\varphi \\
 r_{31} &= \sin\omega * \sin\kappa - \cos\omega * \sin\varphi * \cos\kappa \\
 r_{32} &= \sin\omega * \cos\kappa + \cos\omega * \sin\varphi * \sin\kappa \\
 r_{33} &= \cos\omega * \cos\varphi
 \end{aligned}$$

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

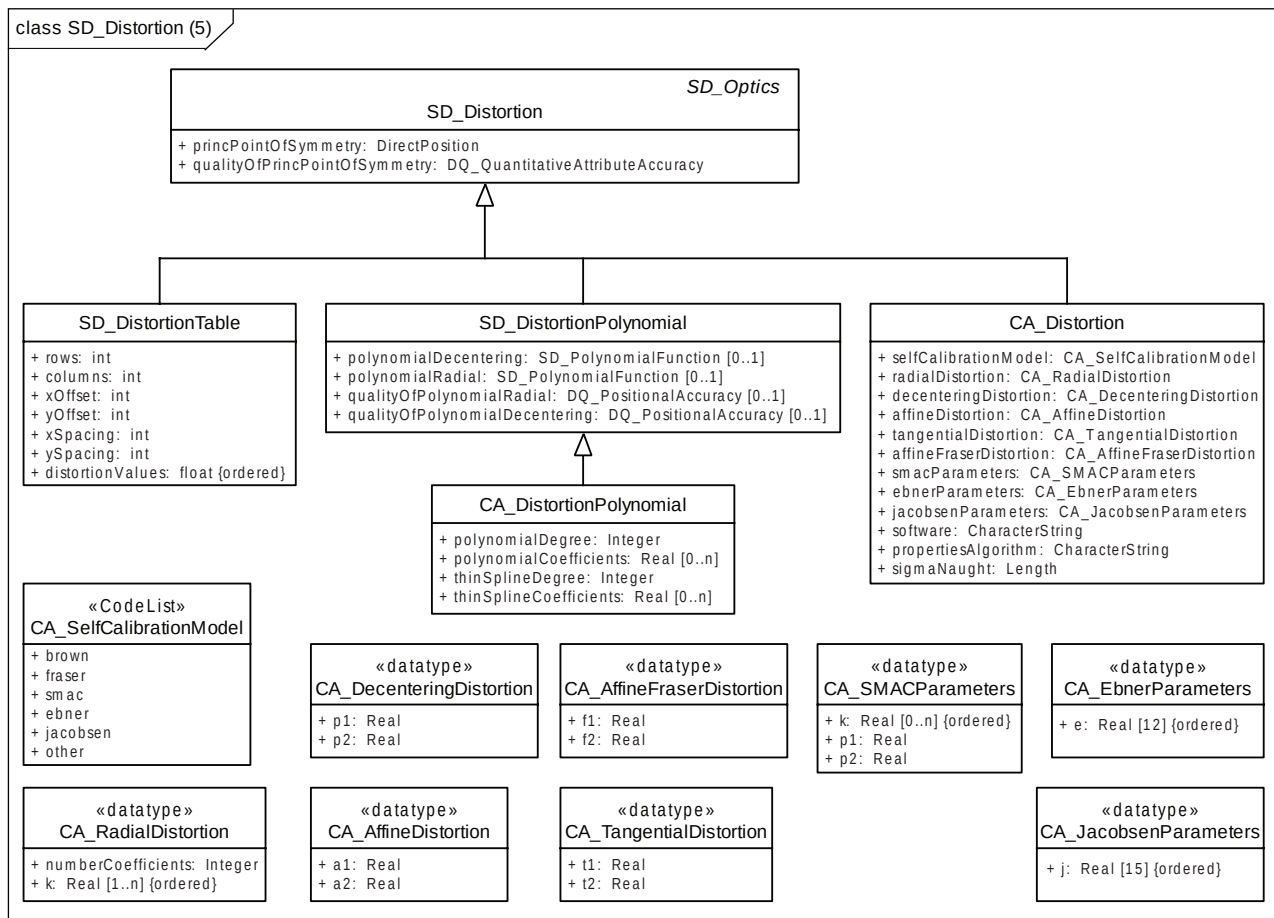
The class CA_GeometricResolution is a data type that defines the geometric resolution counted in line-pairs per length-unit [1/Length]. Its attribute geometricResolution has the data type Real.

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.



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 qualityOfPolynomialDecentering 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

$$n = (u+1)(u+2), \text{ e.g. if } u = 2 \text{ then } n = 12$$

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	$K_0, K_1, K_2, K_3, \dots, K_i$		
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

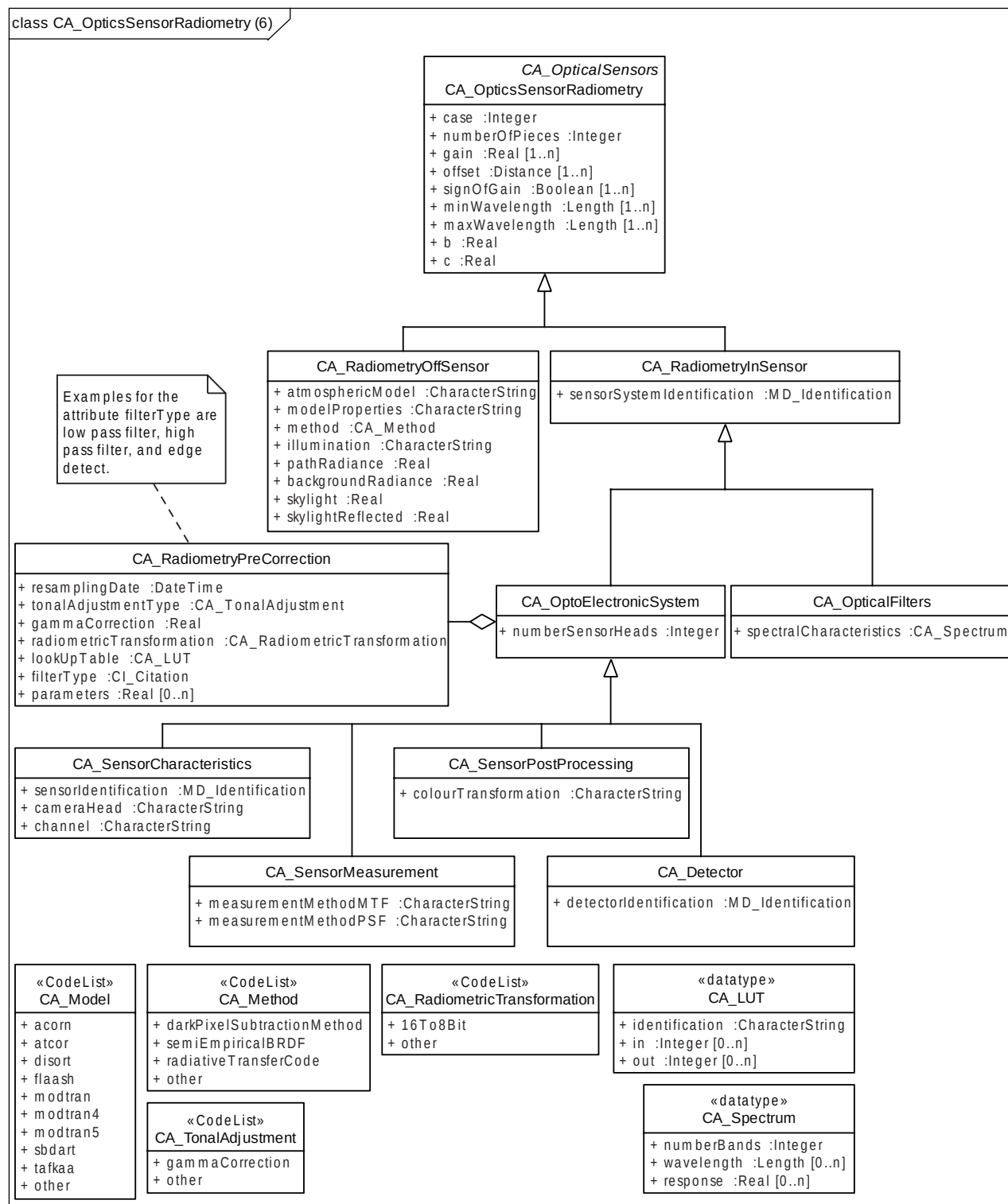
6.3.1 Semantics

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:

$$L_{\text{sensor}}(i,j) = k \cdot \text{DN}(i,j) + d \quad (3)$$

Case 2:

$$L = (\text{DN}-1) \cdot \text{UCC} \quad (4)$$

where

$L_{\text{sensor}}(i,j)$ is at-sensor radiance;
 k is the gain;
 $\text{DN}(i,j)$ 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.