BS ISO 19130-1:2018

BSI Standards Publication

Geographic information — Imagery sensor models for geopositioning

Part 1: Fundamentals

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National foreword

This British Standard is the UK implementation of ISO 19130-1:2018. It supersedes DD ISO/TS 19130:2010, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee IST/36, Geographic information.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Geographic information — Imagery sensor models for geopositioning —

Part 1: Fundamentals

Information géographique — Modèles de capteurs d'images et géopositionnement —

Partie 1: Principes de base

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Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
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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 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 211, *Geographic information/Geomatics.*

This first edition of ISO 19130 cancels and replaces ISO/TS 19130:2010, which has been technically revised.

The main changes compared to the previous edition are:

— part number 1 was added to reflect that ISO 19130 is now divided into several parts;

— normative references are updated to reflect revisions;

— Annex B is updated to reference the updated versions of the ISO geographic information standards.

A list of all the parts in the ISO 19130 series, can be found on the ISO website.

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

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Introduction

The purpose of this document is to specify the geolocation information that an imagery data provider shall supply in order for the user to be able to find the earth location of the data using a Physical Sensor Model (PSM), a True Replacement Model (TRM) or a Correspondence Model (CM). Detailed PSMs are defined for passive electro-optical visible/ IR sensors (frame, pushbroom and whiskbroom) and for an active microwave sensing system (SAR). A set of components from which models for other sensors can be constructed is also provided. Metadata required for geopositioning using a TRM, a CM, or ground control points (GCPs) are also specified. The intent is to standardize sensor descriptions and specify the minimum geolocation metadata requirements for data providers and geopositioning imagery systems.

Vast amounts of data from imaging systems are collected, processed and distributed by government mapping and remote sensing agencies and commercial data vendors. In order for this data to be useful in extraction of geographic information, it requires further processing. Geopositioning, which determines the ground coordinates of an object from image coordinates, is a fundamental processing step. Because of the diversity of sensor types and the lack of a common sensor model standard, data from different producers can contain different parametric information, lack parameters required to describe the sensor that produces the data, or lack ancillary information necessary for geopositioning and analysing the data. Consequently, a separate software package often has to be developed to deal with data from each individual sensor or data producer. Standard sensor models and geolocation metadata allow agencies or vendors to develop generalized software products that are applicable to data from multiple data producers or from multiple sensors. With such a standard, different producers can describe the geolocation information of their data in the same way, thus promoting interoperability of data between application systems and facilitating data exchange.

This document defines the set of metadata elements specified for providing sensor model and other geopositioning data to users. For the case where a PSM is provided, it includes a location model and metadata relevant to all sensors; it also includes metadata specific to whiskbroom, pushbroom, frame, and SAR sensors. It also includes metadata for functional fit geopositioning, where the function is part of a CM or a TRM. This document also provides a schema for all of these metadata elements.

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Geographic information — Imagery sensor models for geopositioning —

Part 1: Fundamentals

1 Scope

This document identifies the information required to determine the relationship between the position of a remotely sensed pixel in image coordinates and its geoposition. It supports exploitation of remotely sensed images. It defines the metadata to be distributed with the image to enable user determination of geographic position from the observations.

This document specifies several ways in which information in support of geopositioning can be provided.

a) It may be provided as a sensor description with the associated physical and geometric information necessary to rigorously construct a PSM. For the case where precise geoposition information is needed, this document identifies the mathematical equations for rigorously constructing PSMs that relate 2D image space to 3D ground space and the calculation of the associated propagated errors. This document provides detailed information for three types of passive electro-optical/ IR sensors (frame, pushbroom and whiskbroom) and for an active microwave sensing system SAR. It provides a framework by which these sensor models can be extended to other sensor types.

b) It can be provided as a TRM, using functions whose coefficients are based on a PSM so that they provide information for precise geopositioning, including the calculation of errors, as precisely as the PSM they replace.

c) It can be provided as a CM that provides a functional fitting based on observed relationships between the geopositions of a set of GCPs and their image coordinates.

d) It can be provided as a set of GCPs that can be used to develop a CM or to refine a PSM or TRM.

This document does not specify either how users derive geoposition data or the format or content of the data the users generate.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 19103:2015, *Geographic information — Conceptual schema language*

ISO 19107, *Geographic information — Spatial schema*

ISO 19108, *Geographic information — Temporal schema*

ISO 19111:2007, *Geographic information — Spatial referencing by coordinates*

ISO 19115-1:2014, *Geographic information — Metadata — Part 1: Fundamentals*

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

ISO 19123, *Geographic information — Schema for coverage geometry and functions*

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ISO 19157:2013, *Geographic information — Data quality*

3 Terms and definitions

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

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

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

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

3.1
active sensing system
sensing system that emits energy that the *sensor* (3.79) uses to perform sensing

3.2
adjustable model parameters
model parameters that can be refined using available additional information, such as *ground control points* (3.42), to improve or enhance modelling corrections

3.3
along-track
direction in which the *sensor* (3.79) platform moves

3.4
aperture reference point
APR
3D location of the centre of the synthetic aperture

Note 1 to entry: It is usually expressed in ECEF *coordinates* (3.11) in metres.

3.5
attitude
orientation of a body, described by the angles between the axes of that body's *coordinate system* (3.13) and the axes of an external coordinate system

[SOURCE: ISO 19116:2004, 4.2, modified – NOTE is deleted.]

3.6
attribute
named property of an entity

Note 1 to entry: In this document, the property relates to a geometrical, topological, thematic, or other characteristic of an entity.

[SOURCE: ISO/IEC 2382:2015, 2121440, modified – Note 1 to entry has been added.]

3.7
azimuth resolution
⟨SAR⟩ resolution in the cross-range direction

Note 1 to entry: This is usually measured in terms of the *impulse response* (3.56) of the *SAR* (3.76) *sensor* (3.79) and processing system. It is a function of the size of the synthetic aperture, or alternatively the dwell time (i.e. a larger aperture results in a longer dwell time results in better resolution).

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3.8
beam width
⟨SAR⟩ useful angular width of the beam of electromagnetic energy

Note 1 to entry: Beam width is usually measured in radians and as the angular width between two points that have 50 % of the power (3 dB below) of the centre of the beam. It is a property of the antenna. Power emitted outside of this angle is too little to provide a usable return.

3.9
broadside
⟨SAR⟩ direction orthogonal to the velocity vector and parallel to the plane tangent to the Earth's *ellipsoid* (3.21) at the nadir point of the *ARP* (3.4)

3.10
calibrated focal length
distance between the *perspective centre* (3.62) and the *image plane* (3.53) that is the result of balancing positive and negative radial lens distortions during *sensor* (3.79) calibration

3.11
coordinate
one of a sequence of *n* numbers designating the position of a point in *n*-dimensional space

Note 1 to entry: In a *coordinate reference system* (3.12), the coordinate numbers are qualified by units.

[SOURCE: ISO 19111:2007, 4.5]

3.12
coordinate reference system
CRS
coordinate system (3.13) that is related to an object by a *datum* (3.17)

Note 1 to entry: For geodetic and vertical datums, the object will be the Earth.

[SOURCE: ISO 19111:2007, 4.8]

3.13
coordinate system
set of mathematical rules for specifying how *coordinates* (3.11) are to be assigned to points

[SOURCE: ISO 19111:2007, 4.10]

3.14
Correspondence Model
CM
functional relationship between ground and *image* (3.47) *coordinates* (3.11) based on the correlation between a set of *ground control points* (3.42) and their corresponding image coordinates

3.15
cross-track
perpendicular to the direction in which the collection platform moves

3.16
data
reinterpretable representation of information in a formalised manner suitable for communication, interpretation, or processing

[SOURCE: ISO/IEC 2382:2015, 2121272]

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3.17
datum
parameter or set of parameters that define the position of the origin, the scale, and the orientation of a *coordinate system* (3.13)

[SOURCE: ISO 19111:2007, 4.14]

3.18
detector
device that generates an output signal in response to an energy input

3.19
Doppler angle
⟨SAR⟩ angle between the velocity vector and the *range vector* (3.72)

3.20
Doppler shift
wavelength change resulting from relative motion of source and *detector* (3.18)

Note 1 to entry: In the *SAR* (3.76) context, it is the frequency shift imposed on a radar signal due to relative motion between the transmitter and the object being illuminated.

3.21
ellipsoid
surface formed by the rotation of an ellipse about a main axis

Note 1 to entry: The Earth ellipsoid is a mathematical ellipsoid figure of the Earth which is used as a reference frame for computations in geodesy, astronomy and the geosciences.

[SOURCE: ISO 19111:2007, 4.17, modified – a new Note 1 to entry replaces NOTE.]

3.22
ellipsoidal coordinate system
geodetic coordinate system
coordinate system (3.13) in which position is specified by *geodetic latitude* (3.30), *geodetic longitude* (3.31) and (in the three-dimensional case) *ellipsoidal height* (3.23)

[SOURCE: ISO 19111:2007, 4.18]

3.23
ellipsoidal height
geodetic height
h
distance of a point from the *ellipsoid* (3.21) measured along the perpendicular from the ellipsoid to this point, positive if upwards or outside of the ellipsoid

Note 1 to entry: Only used as part of a three-dimensional *ellipsoidal coordinate system* (3.22) and never on its own.

[SOURCE: ISO 19111:2007, 4.19]

3.24
error propagation
process of determining the uncertainties of derived quantities from the known uncertainties of the quantities on which the derived quantity is dependent

Note 1 to entry: Error propagation is governed by the mathematical function relating the derived quantity to the quantities from which it was derived.

3.25
external coordinate reference system
coordinate reference system (3.12) whose *datum* (3.17) is independent of the object that is located by it

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3.26
fiducial centre
point determined on the basis of the camera *fiducial marks* (3.27)

Note 1 to entry: When there are four fiducial marks, fiducial centre is the intersection of the two lines connecting the pairs of opposite fiducial marks.

3.27
fiducial mark
index marks, typically four or eight rigidly connected with the camera body, which form *images* (3.47) on the film negative and define the *image coordinate reference system* (3.48)

Note 1 to entry: When a camera is calibrated the distances between fiducial marks are precisely measured and assigned *coordinates* (3.11) that assist in correcting for film distortion.

3.28
frame sensor
sensor (3.79) that detects and collects all of the *data* (3.16) for an *image* (3.47) (frame/rectangle) at an instant of time

3.29
geodetic datum
datum (3.17) describing the relationship of a two- or three-dimensional *coordinate system* (3.13) to the Earth

Note 1 to entry: In most cases, the geodetic datum includes an *ellipsoid* (3.21) description.

[SOURCE: ISO 19111:2007, 4.24, modified – Note 1 to entry has been added.]

3.30
geodetic latitude
ellipsoidal latitude
φ
angle from the equatorial plane to the perpendicular to the *ellipsoid* (3.21) through a given point, northwards treated as positive

[SOURCE: ISO 19111:2007, 4.25]

3.31
geodetic longitude
ellipsoidal longitude
λ
angle from the prime meridian plane to the meridian plane of a given point, eastward treated as positive

[SOURCE: ISO 19111:2007, 4.26]

3.32
geoid
equipotential surface of the Earth's gravity field which is everywhere perpendicular to the direction of gravity and which best fits mean sea level either locally or globally

[SOURCE: ISO 19111:2007, 3.27]

3.33
geographic information
information concerning phenomena implicitly or explicitly associated with a location relative to the Earth

[SOURCE: ISO 19101-1:2014, 4.1.18]

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3.34
geolocating
geopositioning (3.36) an object using a *Physical Sensor Model* (3.63)or a *True Replacement Model* (3.86)

3.35
geolocation information
information used to determine geographic location corresponding to *image* (3.47) location

[SOURCE: ISO 19115-2:2009, 4.11]

3.36
geopositioning
determination of the geographic position of an object

Note 1 to entry: While there are many methods for geopositioning, this document is focused on geopositioning from *image* (3.47) *coordinates* (3.11).

3.37
georeferencing
geopositioning (3.36) an object using a *Correspondence Model* (3.14)derived from a set of points for which both ground and *image* (3.47) *coordinates* (3.11) are known

3.38
gimbal
mechanical device consisting of two or more rings connected in such a way that each rotates freely around an axis that is a diameter of the next ring toward the outermost ring of the set

Note 1 to entry: An object mounted on a three-ring gimbal will remain horizontally suspended on a plane between the rings regardless as to the stability of the base.

3.39
grazing angle
⟨SAR⟩ vertical angle from the local surface tangent plane to the *slant range direction* (3.70)

3.40
grid
network composed of two or more sets of curves in which the members of each set intersect the members of the other sets in an algorithmic way

Note 1 to entry: The curves partition a space into grid cells.

[SOURCE: ISO 19123:2005, 4.1.23]

3.41
grid coordinates
sequence of two or more numbers specifying a position with respect to its location on a *grid* (3.40)

[SOURCE: ISO 19115-2:2009, 4.16]

3.42
ground control point
GCP
point on the earth that has an accurately known geographic position

[SOURCE: ISO 19115-2:2009, 4.18]

3.43
ground range
⟨SAR⟩ magnitude of the *range vector* (3.72) projected onto the ground

Note 1 to entry: Ground range of an *image* (3.47) is represented by the distance from the nadir point of the antenna to a point in the scene. Usually measured in the horizontal plane, but can also be measured as true distance along the ground, DEM, *geoid* (3.32) or *ellipsoid* (3.21) surface.

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3.44
ground reference point
GRP
3D position of a reference point on the ground for a given synthetic aperture

Note 1 to entry: It is usually the centre point of an *image* (3.47) (Spotlight) or an image line (Stripmap). It is usually expressed in ECEF *coordinates* (3.11) in metres.

3.45
ground sampling distance
linear distance between *pixel* (3.64) centres on the ground

Note 1 to entry: This definition also applies for water surfaces.

3.46
gyroscope
device consisting of a spinning rotor mounted in a *gimbal* (3.38) so that its axis of rotation maintains a fixed orientation

Note 1 to entry: The rotor spins on a fixed axis while the structure around it rotates or tilts. In airplanes, the pitch and orientation of the airplane is measured against the steady spin of the gyroscope. In space, where the four compass points are meaningless, the gyroscope's axis of rotation is used as a reference point for navigation. An inertial navigation system includes three gimbal-mounted gyroscopes, used to measure roll, pitch, and yaw.

3.47
image
gridded coverage whose *attribute* (3.6) values are a numerical representation of a physical parameter

Note 1 to entry: The physical parameters are the result of measurement by a *sensor* (3.79) or a prediction from a model.

[SOURCE: ISO 19115-2:2009, 4.19]

3.48
image coordinate reference system
coordinate reference system (3.12) based on an *image datum* (3.49)

[SOURCE: ISO 19111:2007, 4.30]

3.49
image datum
engineering *datum* (3.17) which defines the relationship of a *coordinate system* (3.13) to an *image* (3.47)

[SOURCE: ISO 19111:2007, 4.31]

3.50
image distortion
deviation between the actual location of an *image point* (3.54) and the location that theoretically would result from the geometry of the imaging process without any errors

3.51
image formation
⟨SAR⟩ process by which an *image* (3.47) is generated from collected phase history data in a *SAR* (3.76) system

3.52
image-identifiable ground control point
ground control point (3.42) associated with a marker or other object on the ground that can be recognized in an *image* (3.47)

Note 1 to entry: The ground control point may be marked in the image, or the user may be provided with an unambiguous description of the ground control point so that it can be found in the image.

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3.53
image plane
plane behind an imaging lens where *images* (3.47) of objects within the depth of field of the lens are in focus

3.54
image point
point on the *image* (3.47) that uniquely represents an *object point* (3.60)

3.55
imagery
representation of phenomena as *images* (3.47) produced by electronic and/or optical techniques

Note 1 to entry: In this document, it is assumed that the phenomena have been sensed or detected by one or more devices such as radars, cameras, photometers and IR and multispectral scanners.

[SOURCE: ISO 19101-2:2018, 3.14]

3.56
impulse response
IPR
width of the return generated by a small point reflector, which equates to the smallest distance between two point reflectors that can be distinguished as two objects

3.57
incident angle
vertical angle between the line from the detected element to the *sensor* (3.79)and the local surface normal (tangent plane normal)

3.58
internal coordinate reference system
coordinate reference system (3.12) having a *datum* (3.17) specified with reference to the object itself

3.59
metadata
information about a *resource*

[SOURCE: ISO 19115-1:2014, 4.10]

3.60
object point
point in the object space that is imaged by a *sensor* (3.79)

Note 1 to entry: In *remote sensing* (3.74) and aerial photogrammetry an object point is a point defined in an Earth-fixed *coordinate reference system* (3.12).

3.61
passive sensor
sensor (3.79) that detects and collects energy from an independent source

EXAMPLE Many optical sensors collect reflected solar energy.

3.62
perspective centre
projection centre
point located in three dimensions through which all rays between *object points* (3.60) and *image points* (3.54) appear to pass geometrically

3.63
Physical Sensor Model
PSM
sensor model (3.80) based on the physical configuration of a sensing system

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3.64
pixel
smallest element of a digital *image* (3.47) to which *attributes* (3.6) are assigned

Note 1 to entry: This term originated as a contraction of "picture element".

Note 2 to entry: Related to the concept of a *grid* (3.40) cell.

[SOURCE: ISO 19101-2:2018, 3.28]

3.65
platform coordinate reference system
engineering *coordinate reference system* (3.12) fixed to the collection platform within which positions on the collection platform are defined

3.66
principal point of autocollimation
point of intersection between the *image plane* (3.53) and the normal from the *perspective centre* (3.62)

3.67
principal point of best symmetry
centre of the circles of equal distortion of the lens positioned in the *image plane* (3.53)

3.68
pushbroom sensor
sensor (3.79) that collects a single *cross-track* (3.15) *image* (3.47) line at one time and constructs a larger image from a set of adjacent lines resulting from the *along-track* (3.3) motion of the sensor

3.69
range bin
⟨SAR⟩ group of radar returns that all have the same range

3.70
range direction
slant range direction
⟨SAR⟩ direction of the *range vector* (3.72)

3.71
range resolution
spatial **resolution** in the *range direction* (3.70)

Note 1 to entry: For a *SAR (3.76) sensor (3.79)*, it is usually measured in terms of the *impulse response* (3.56) of the *sensor* (3.79) and processing system. It is a function of the bandwidth of the pulse.

3.72
range vector
vector from the antenna to a point in the scene

3.73
rectified grid
grid (3.40) for which there is an affine transformation between the *grid coordinates* (3.41) and the *coordinates* (3.11) of an *external coordinate reference system (3.25)*

Note 1 to entry: If the *coordinate reference system* (3.12) is related to the Earth by a *datum* (3.17), the grid is a georectified grid.

[SOURCE: ISO 19123:2005, 4.1.32]

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3.74
remote sensing
collection and interpretation of information about an object without being in physical contact with the object

[SOURCE: ISO 19101-2:2018, 3.33]

3.75
resolution (of a sensor)
smallest difference between indications of a *sensor* (3.79) that can be meaningfully distinguished

Note 1 to entry: For *imagery* (3.55), resolution refers to radiometric, spectral, spatial and temporal resolutions.

[SOURCE: ISO 19101-2:2018, 3.34]

3.76
Synthetic Aperture Radar
SAR
imaging radar system that simulates the use of a long physical antenna by collecting multiple returns from each target as the actual antenna moves along the track

Note 1 to entry: The electromagnetic radiation is at microwave frequencies and is sent in pulses.

3.77
scan mode
SAR (3.76) mode in which the antenna beam is steered to illuminate a swath of ground at various angles relative to flight path throughout the collection

Note 1 to entry: Steering the antenna also allows dwell time to be increased and provides the ability to collect strips at angles non-parallel to the flight direction and with better resolution than *stripmap mode* (3.85).

3.78
ScanSAR mode
special case of *stripmap mode* (3.85) that uses an electronically steerable antenna to quickly change the swath being imaged during collection to collect multiple parallel swaths in one pass

3.79
sensor
element of a measuring system that is directly affected by a phenomenon, body, or substance carrying a quantity to be measured

[SOURCE: ISO/IEC Guide 99:2007, 3.8]

3.80
sensor model
⟨geopositioning⟩ mathematical description of the relationship between the three-dimensional object space and the 2D plane of the associated *image* (3.47) produced by a *sensor* (3.79)

3.81
slant plane
⟨SAR⟩ plane that passes through the *sensor* (3.79) velocity vector and the GRP

3.82
slant range
⟨SAR⟩ magnitude of the *range vector* (3.72)

3.83
spotlight mode
⟨SAR⟩ *SAR* (3.76) mode in which the antenna beam is steered to illuminate one area during collection

Note 1 to entry: Spotlight mode provides the ability to collect higher resolution SAR *data* (3.16) over relatively smaller patches of ground surface.

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3.84
squint angle
⟨SAR⟩ angle measured from the *broadside* (3.9) direction vector to the *range direction* (3.70) vector in the *slant plane* (3.81)

3.85
stripmap mode
⟨SAR⟩ *SAR* (3.76) mode in which the antenna beam is fixed throughout the collection of an *image* (3.47)

Note 1 to entry: *Doppler angle* (3.19) in processed products is fixed for all *pixels* (3.64). It provides the ability to collect SAR *data* (3.16) over strips of land over a fixed swath of *ground range* (3.43) parallel to the direction of flight.

3.86
True Replacement Model
TRM
model using functions whose coefficients are based on a *Physical Sensor Model* (3.63)

3.87
whiskbroom sensor
sensor (3.79) that sweeps a *detector* (3.18) forming *cross-track* (3.15) *image* (3.47) line(s) and constructs a larger image from a set of adjacent lines using the *along-track* (3.3) motion of the sensor's collection platform

4 Symbols and abbreviated terms

ARP	Aperture Reference Point
CCD	Charge-Coupled Device
CCS	Common Coordinate System
CM	Correspondence Model
CCS	Common Coordinate System
CRS	Coordinate Reference System
DEM	Digital Elevation Model
DLT	Direct Linear Transform
ECEF	Earth-Centred, Earth-Fixed
ENU	East-North-Up
EO	Exterior Orientation
FSP	Flight Stabilization Platform
GCP	Ground Control Point
GNSS	Global Navigation Satellite System
GRP	Ground Reference Point
GSD	Ground Sample Distance
IMU	Inertial Measurement Unit

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INS	Inertial Navigation System
IRF	Inertial Reference Frame
IPR	Impulse Response
IR	Infrared
MSL	Mean Sea Level
NED	North-East-Down
PHD	Phase History Data
PSM	Physical Sensor Model
RAR	Real Aperture Radar
RMS	Root Mean Square
RPC	Rational Polynomial Coefficient
RSM	Replacement Sensor Model
SAR	Synthetic Aperture Radar
SCS	Sensor Coordinate System
TRM	True Replacement Model
VPHD	Video Phase History Data
WGS 84	World Geodetic System 1984
2D	Two-dimensional
3D	Three-dimensional

5 Conformance

This document specifies four conformance classes. There is one conformance class for each of the methods specified for providing geopositioning information. Any set of geopositioning information claiming conformance to this document shall satisfy the requirements for at least one conformance class as specified in Table 1. The requirements for each class are shown by the presence of an X in the boxes for all clauses in the application test suite (ATS) required for that class. If the requirement is conditional, the box contains a C.

Table 1 — Conformance classes

Conformance classes		Subclause										
		A.1	A.2.1	A.2.2	A.3.1	A.3.2	A.3.3	A.3.4	A.3.5	A.4	A.5	A.6
Correspondence model		X	X	X						X		X
Physical sensor model	SAR	X			X	X	X		X			
	electro-optical	X			X	X	X	X				
True replacement model		X								X	X	
GCP collection		X	X	X	C	C	C	C	C	C	C	C

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6 Notation

Clauses 7, 8, and 9 of this document present a conceptual schema, specified in the Unified Modeling Language (UML), describing the characteristics of sensor models. ISO 19103 describes the way in which UML is used in the ISO 19100 family of standards. It differs from standard UML only in the existence and interpretation of some special stereotypes, in particular, "CodeList" and "Union". ISO 19103 specifies the basic data types used in the UML model and the data dictionary in this document.

Annex B contains a data dictionary for the UML diagrams in this schema.

ISO 19103 requires that names of UML classes, with the exception of basic data type classes, include a two-letter prefix that identifies the standard and the UML package in which the class is defined. Table 2 lists the prefixes used in this document, the document in which each is defined and the package each identifies. UML classes defined in this document belong to a package named Sensor Data and have the two letter prefix SD.

Table 2 — UML class prefixes

Prefix	International standard	Package
CI	ISO 19115-1	Citation
CV	ISO 19123	Coverages
DQ	ISO 19157	Data quality
GM	ISO 19107	Geometry
MD	ISO 19115-1	Metadata
MI	ISO 19115-2	Metadata for imagery
SC	ISO 19111	Spatial coordinates
SD	ISO 19130-1	Sensor data
TM	ISO 19108	Temporal schema

7 Image geopositioning: Overview and common elements

7.1 General

An image is depicted as a 2D set of contiguous pixels. Associated with each pixel in the image is either a single response value, as in a panchromatic image; three response values in red, green, and blue, as in a colour image; or many values, as in multi-and hyper-spectral images. Geopositioning information applies to the pixel, regardless of how many response values are associated with that pixel.

Image geopositioning is the process of determining the Earth coordinates of an object from image coordinates. Geolocation information is the information necessary for the geopositioning methods to work. Features in Earth imagery can be geopositioned by different approaches. The data provider shall identify to the user which method was used.

In order to determine the 3D Earth coordinates of features and the quality associated with those coordinates (rigorously expressed by covariance matrices) accurately, two approaches exist, both ultimately based on the physical configuration of the sensor:

a) Physical Sensor Models (PSMs)

b) True Replacement Models (TRMs)

A third approach is based on:

c) Correspondence Models (CMs)

The most rigorous approach for geopositioning of imagery is to use the mathematical representation of the physics and geometry of the image sensing system, which is referred to as the PSM. That

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model is used extensively in photogrammetric applications for precise geopositioning. In order to precisely determine geoposition from imagery, certain steps need to be performed. The first and most fundamental step is to construct, mathematically, the sensor model that corresponds to the type of sensor under consideration. Then, information relating the sensing event to the ground reference coordinate system is needed to apply the model to a given image. This information can be in one of two forms:

a) accurate data about the position, attitude, and dynamics of the sensor during imaging; or

b) ground control information such as a set of GNSS-determined GCPs.

TRMs are produced using PSMs. The equations that describe the sensor and its relationship to the Earth CRS are replaced with a set of equations that directly describe the relationship between image coordinates and Earth coordinates.

Geopositioning that applies correspondence modelling, called georeferencing, uses image information and GCPs only. CMs are quite varied and may deal with only horizontal (e.g., longitude and latitude) coordinates, or with all three coordinates (e.g., longitude, latitude and elevation). They all have in common the fact that they do not make use of the PSM and consequently cannot apply rigorous error propagation. Thus, CMs are generally less accurate than methods based on PSMs. Neither a geometric model of the sensor that took the image nor information about its position and orientation is required. This georeferencing method has been widely applied to remotely sensed imagery. For instance, the geographic location of an image can be established using a 2D polynomial function based on a number of common points that relate the image to the surface of the Earth. The simplest way to georeference an image is by defining the Earth coordinates of the image corners.

This document defines the geopositioning information for supporting the above-stated approaches for geopositioning images. Clause 8 covers the PSM approach and Clause 9 covers TRMs and CMs.

7.2 Type of geopositioning information

Geopositioning information shall be provided in one of the ways shown in Figure 1:

a) A set of GCPs (MI_GCPCollection) and optional quality information as specified in ISO 19115-2 and further specified in 7.4. The recipient can use this information to generate his own fitting function for use in a CM.

b) A sensor model (SD_SensorModel) as specified in this document. An instance of SD_SensorModel provides geopositioning information for the single image identified by the attribute forImageID. SD_SensorModel is an aggregate of one or more instances of one, but no more than one, of the three sensor model types specified in this document. This allows for spatial segmentation of the image such that there is one instance of the model type for each segment. The three specified sensor model types are:

    1) Physical Sensor Model (SD_PhysicalSensorModel),

    2) True Replacement Model (SD_TrueReplacementModel), and

    3) Correspondence Model (SD_CorrespondenceModel).

The classes shown in Figure 1, their attributes and their associations shall be used as specified in the data dictionary of B.2.1.

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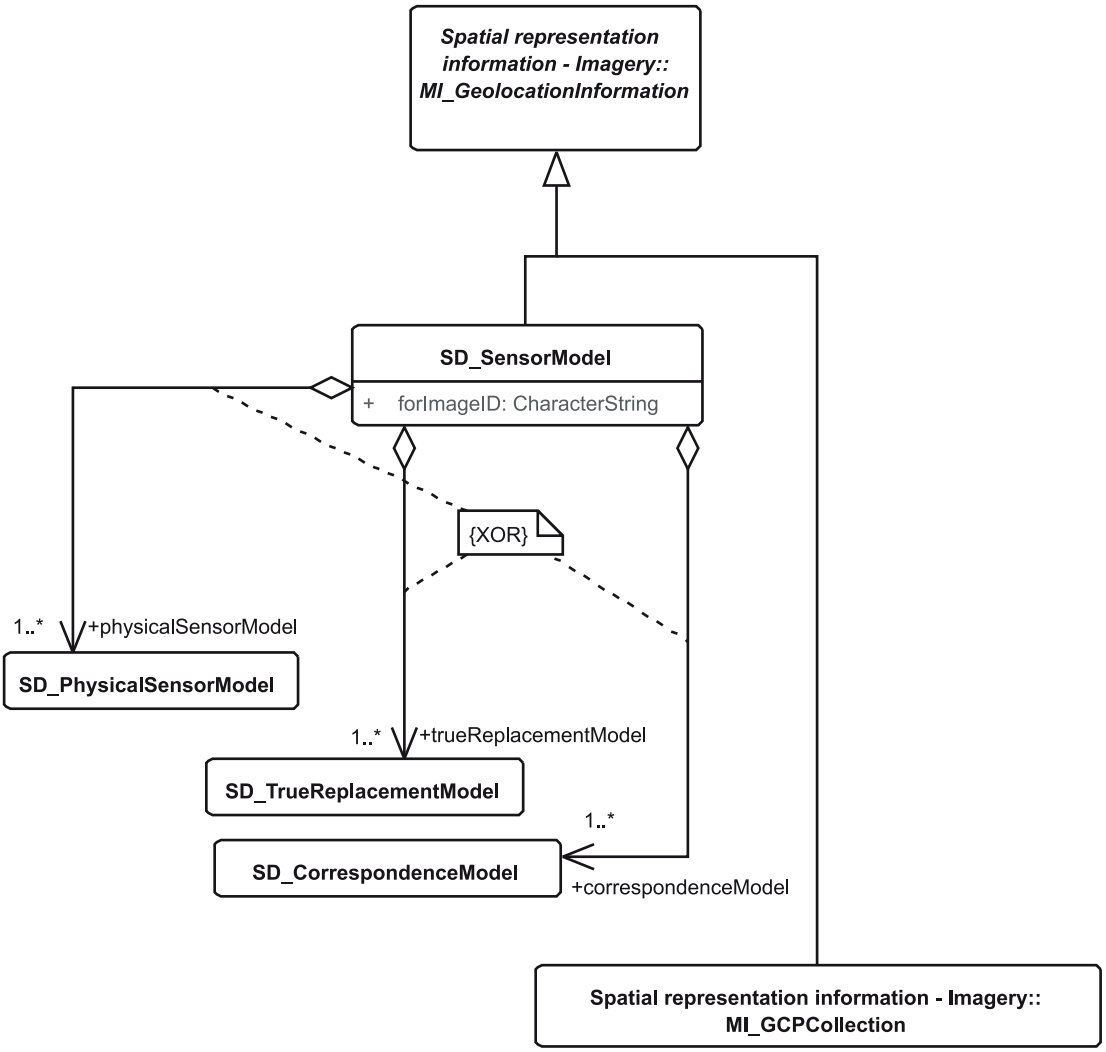

Figure 1 — SD_SensorModel

7.3 Calibration data

7.3.1 General

Sensor calibration is a significant input to sensor modelling. There are two types of calibration data: geometric and radiometric. Geometric calibration data is critical for precise geopositioning from imagery. Radiometric calibration is needed for quantitative estimation of geophysical parameters and interpretation of the physical and geographical significance of the measurements.

7.3.2 Geometric calibration

Sensor geometric calibration data are either available in the metadata from laboratory calibration or can actually be determined during photogrammetric processing of the imagery. Calibration parameters are defined according to the type of sensor. For electro-optical sensors, common parameters include calibrated focal length, principal point offset, radial lens distortion coefficients, tangential or decentring lens distortion coefficients and sensor array distortions such as differential scale and skew.

7.3.3 Radiometric calibration

Radiometric calibration refers to operations intended to remove systematic or random noise that affect the amplitude of the image function. Radiometric calibration includes correcting the data for sensor

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irregularities and unwanted sensor or atmospheric noise, and converting the data so they accurately represent the reflected or emitted radiation measured by the sensor.

This specification is concerned with those aspects of radiometric calibration that involve adjustment of the non-uniform response of the different elements of the sensor array to improve the relative spectral and temporal fidelity of the current data acquisition. In particular, the process which normalizes these responses and the values from in-flight and laboratory measured pre-flight radiometric empirical adjustments shall be available.

The image location of pixels corresponding to failed or degraded detectors and line losses as well as the methods used to address such failure or degradation shall also be recorded and available.

Except for atmospheric correction, radiometric corrections for environmental effects due to seasons, terrain, sensor operation, and sampling methods within and across data acquisitions are outside the scope of this document.

7.4 Ground control points

7.4.1 General

As specified by ISO 19115-2, geolocation information may consist of no more than a collection of GCPs. In that approach, a set of GCPs and their corresponding image points are identified and provided to the user, who can then derive the object (ground) coordinates of other image points based on these correspondences. The method used for the derivation of these additional point coordinates is left to the user's choice, depending upon the application. For example, a 3D-to-2D or 2D-to-2D function may be first fit, for 3D and 2D control, respectively, and then the function used to calculate the coordinates of the additional points. Alternatively, an interpolation scheme may be used such as nearest neighbour, bilinear or bicubic for 2D; and trilinear or triquadratic for 3D.

NOTE For 3D-to-2D transformations, it is not possible to derive the 3D object coordinates of an additional point from a single image.

However, GCPs are also used in the development of sensor models and may be provided as ancillary information with any sensor model. They are often used to adjust the values of parameters for PSMs and TRMs and are the basis from which a CM is developed.

7.4.2 Control point types

A full GCP consists of three parameters: two horizontal coordinates, (X, Y) and one vertical coordinate (Z). A horizontal GCP has no vertical coordinate and a vertical GCP has horizontal coordinates. A few horizontal GCPs may suffice for small scale applications with limited accuracy requirements. More points and full GCPs are required for greater accuracy.

The use of GCPs to georeference an image requires knowledge of both the object space coordinates of a point on the ground and the position of the image of that point in an image. There are two mechanisms for specifying the image position.

One method is to mark the GCP in the image or to provide the user an unambiguous description of the GCP so that the user can find the image of the GCP and determine its image coordinates. A common mechanism for doing this is to place a distinctive marker on the ground prior to image acquisition. The GCP might also be associated with an image-identifiable feature on the ground.

The second method is to provide previously determined image coordinates for each GCP. Often, the image coordinates of these points are determined by using a PSM. This means is often used because the organization responsible for image acquisition does not wish to reveal detailed characteristics of the sensor to users of the imagery.

There are also two mechanisms for providing GCP information to the user. One is to provide all information with the image; the other is to provide a pointer to a remote source of the information. The

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second method is often used when the image provider wishes to provide a functional fit model and to restrict access to information about the GCPs.

7.4.3 Control point schema

Figure 2 presents a UML model for GCPs. The classes shown in Figure 2, their attributes and their associations shall be used as described in the data dictionary of B.2.2 and in ISO 19107, ISO 19115-1, ISO 19115-2 and ISO 19123.

MI_GCPCollection is a set of GCPs as defined in ISO 19115-2.

The class MI_GCP specifies a GCP as defined in ISO 19115-2. The attribute geographicCoordinates provides the ground coordinates of the GCP using the data type DirectPosition specified in ISO 19107. DirectPosition has an association to the CRS to which the position is referenced.

The subclass SD_LocationGCP specifies a GCP for which image coordinates have been determined. The attribute gridCoordinates contains those coordinates using the data type CV_GridCoordinates specified in ISO 19123.

The subclass SD_ImageIdentifiableGCP specifies a GCP that is either marked in the image or described so that the user can find its image. The attribute description provides a description of the GCP sufficient to enable the user to find the image of the GCP in the image to be geopositioned.

The class SD_GCPRepository is an optional library of GCPs that may be used as a remote source of control point information if such information is not provided with the image. The attribute accessRestricted indicates that the image provider wishes to control or restrict access to the GCP data. A value of 'true' indicates that access is restricted, while a value of 'false' indicates that the data is publicly available. The attribute accessInformation uses the data type CI_Contact specified in ISO 19115-1. If access is restricted, this attribute provides information for a point of contact who may authorize access to the data; if access is unrestricted, the attribute identifies the mechanism for obtaining the GCP data.

The class SD_GriddedGCPCollection represents a collection of instances of SD_LocationGCP that is structured as a rectified grid. The GCPs can be regularly spaced either in image space defined by SD_ImageGridGCPCollection, where CV_GridCoordinates defines the location of the first GCP in the image space, or in an object space defined by SD_ObjectGridGCPCollection, where DirectPosition is the origin of the grid in object space.

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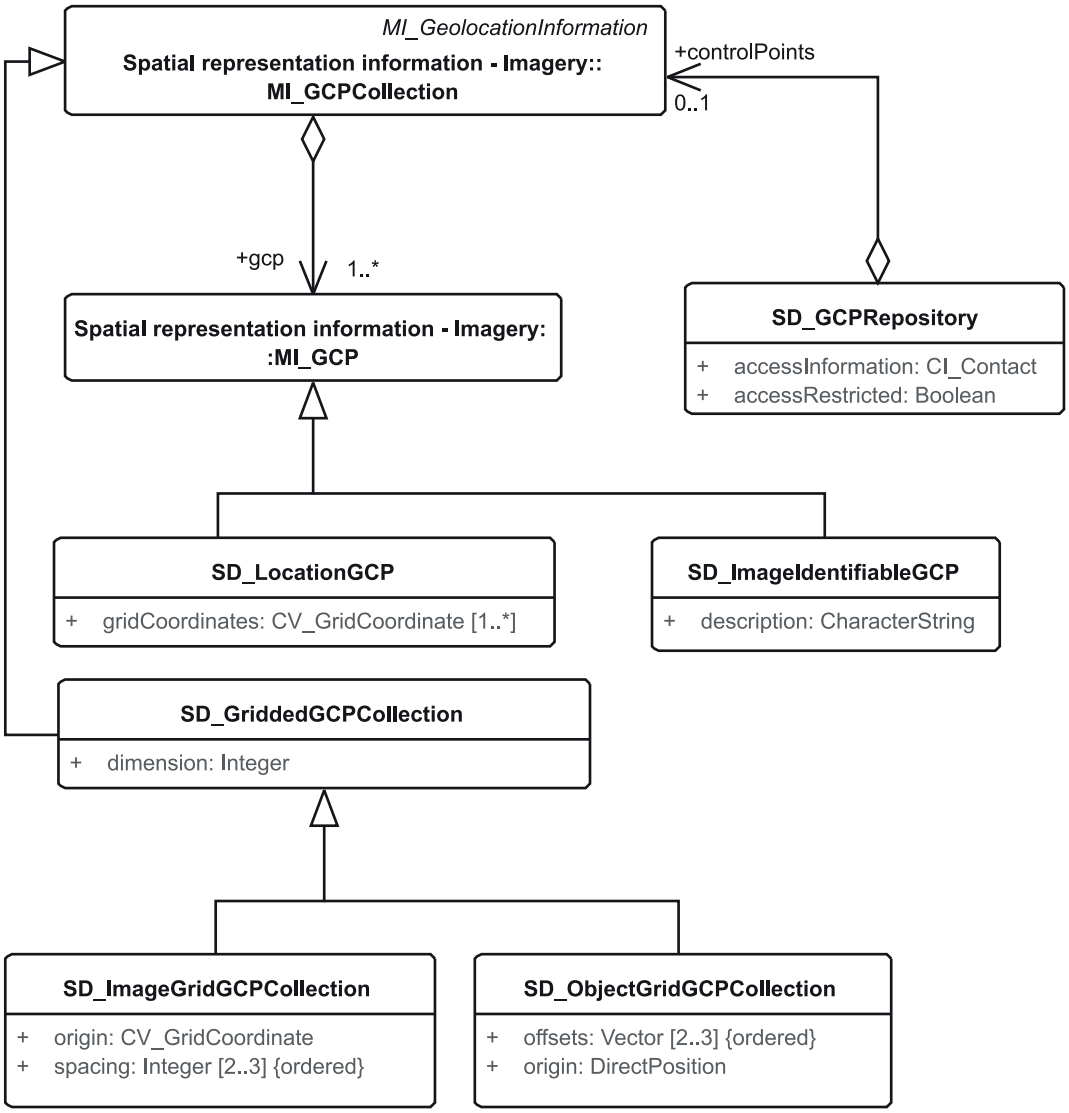

Figure 2 — GCP model

8 Physical Sensor Models

8.1 Sensor types

8.1.1 General

Remote sensors can be classified in different ways. They can be classified, for example, by their mounting platforms, such as spaceborne and airborne, or by the measurand of the sensor, e.g., optical radiation, microwave energy, and sonar (acoustic) energy.

A sensor collects radiation and reports its intensity, usually as a function of position. Separate components generally perform the functions that are part of the process. A pointing system determines the direction from which radiation comes. An optical or antenna system collects the radiation incident on the instrument and directs it to the detector. A detector measures the intensity of the incident radiation. Each type of sensor has its own components to perform these functions. Parameters describing components such as the imaging focal plane and SCSs, the positions of these two coordinate systems, and the angles and offset between them are used in geolocating. Precise geolocation requires information about the quality (ISO 19157) of the parameters.

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Sensor systems and their components are described in 8.1.2 through 8.1.5. Positions of and in a sensor system shall be expressed in a coordinate system as defined in Annex C. Geolocation using each of the sensor types is described in greater detail in an informative annex for that type.

8.1.2 Frame sensor

A frame sensor is one that acquires all of the data for an image (frame) at a single instant of time. Typically, a sensor of this class has a fixed exposure and consists of a 2D detector array, e.g. a CCD array. While "sensor" refers to digital collectors, "camera" is typically used to denote film-based collectors. Although the descriptions in this document are of electro-optical (visible/near IR) frame sensors, the definitions and development apply equally to film and thermal IR array sensors.

A film camera is called a frame camera if it has a frame with fiducial marks that allow the determination of the position of the film in the sensor CRS. During the exposure, the fiducial marks are imaged on the film border. For the purposes of this document, a frame camera is treated as a source of digital data. An image recorded on film needs to be scanned if a digital image is desired. The images of the fiducial marks allow for the 3D algorithmic reconstruction of the perspective centre. This leads to the complete reconstruction of the bundle of the rays to all object points. After the film has been scanned, the position of every pixel of the image is known or can be determined in the area sensor CRS. A digital frame sensor has sensor elements that have individual known positions in the area sensor CRS.

Frame sensors with several heads are in use. Joining the partial images is a matter of the individual post-processing software of the sensor system. This document always refers to the complete image, independent of whether it is joined partial images or taken at one shot such as a film image.

Figure 3 depicts the geometry of a frame sensor. With frame sensors, the central perspective model relates image points to object points. This model represents all light rays from the object, e.g. the surface of the Earth, to the image as running through one single point that is called the perspective centre L. To allow reconstruction of every ray according to its point measurement on the image plane, the 3D position of the perspective centre L in relation to the image plane shall be provided. This relation shall be established through a 3D image CRS in which both the image point and the perspective centre can be expressed. In the case of a frame camera, the relation of the image CRS to the image is defined by the calibrated positions of the fiducial marks. The 3D position of the perspective centre is defined by the coordinates of the principal point of autocollimation (PPA), x_0 and y_0 and by the calibrated focal length f_c (z-value). The origin of the x, y, z coordinate system in Figure 3 is shifted from the Indicated Principal Point, IPP (or fiducial centre) to the PPA (see Figure C.12).

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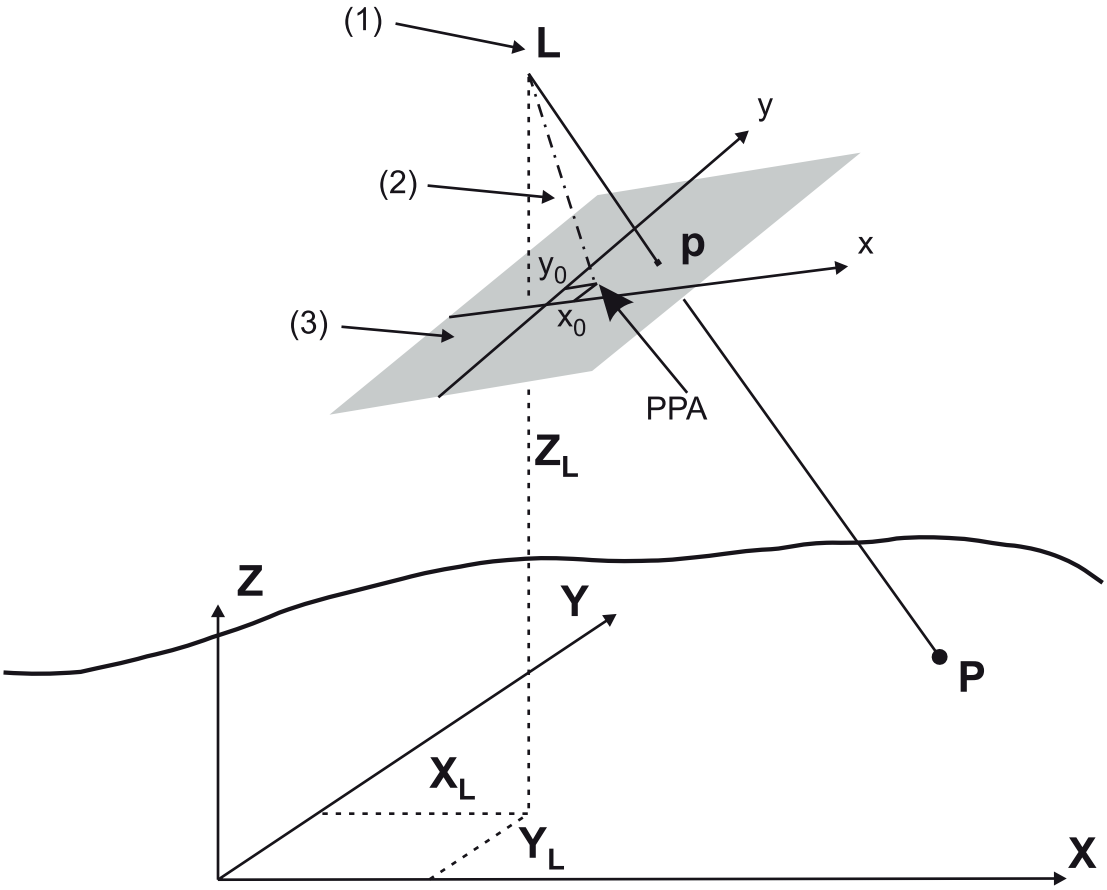

Key

1 sensor perspective centre

2 calibrated focal length, f_c

3 positive image plane

Figure 3 — Frame sensor image and perspective centre

Frame sensors are discussed in more detail in Annex D.

8.1.3 Pushbroom sensor

A pushbroom sensor is a digital collector with a collection array made up of a line of detectors at the focal plane to scan over a two dimensional scene. For the pushbroom sensor model, the along track displacement of all recorded pixels of a scan line is set to zero. For the across track pixel coordinates, a constant spacing of successive pixels is assumed. A typical pushbroom sensor contains one or more linear arrays of detectors. The array is lined up perpendicular to the direction of platform motion, allowing the sensor to simultaneously collect and record data for a complete line of samples. In Figure 4, f is the calibrated focal length, h_g height above surface, s the swath width, s' the length of the detector array, Ω the field of view, a' the sensor detector size in the cross-track direction and the corresponding image plane field of view (IFOV), a the GSD across track, b' the sensor detector size in the along track direction and the corresponding image plane field of view and $b = v\Delta t$ the GSD along track, where v is the along-track platform velocity and Δt is the dwell time.

To obtain geolocation using a PSM for a pushbroom sensor, it is necessary to know its geometric properties, including the focal plane coordinate system and the number, size and spatial distribution of detectors. If the data provider intends to let the data users derive geolocation using a PSM, this information shall be provided to them. Pushbroom sensors are described in more detail in Annex E.

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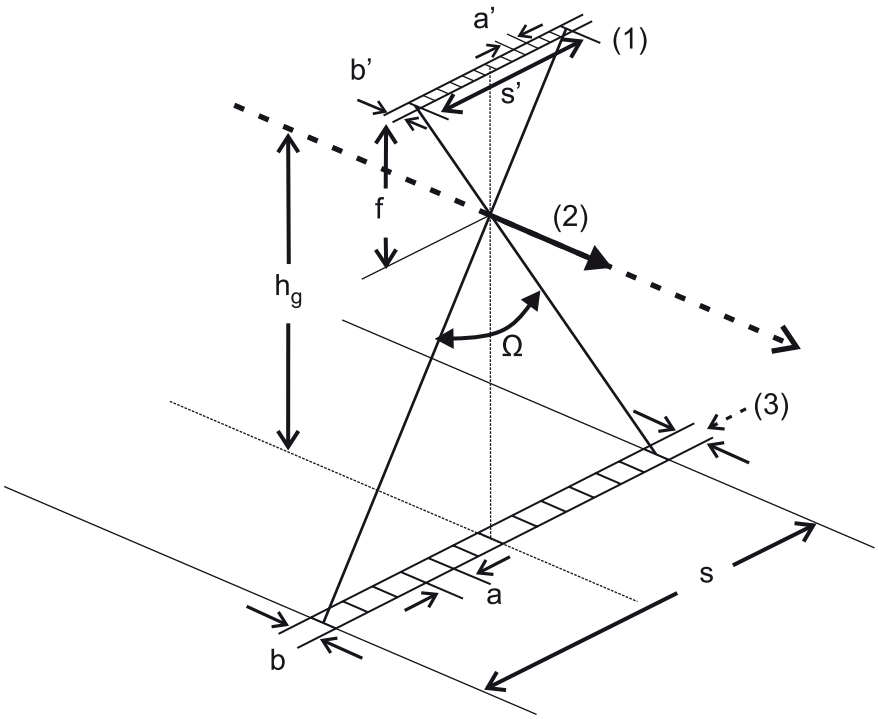

Key

1 focal plane

2 velocity vector

3 corresponds to Δt

Figure 4 — Optical layout of a pushbroom array

8.1.4 Whiskbroom sensor

A whiskbroom scanning sensor has one or more detectors scanning perpendicular to the platform moving direction, allowing the sensor to simultaneously take one or more scan lines of data during a scan, as shown in Figure 5. In Figure 5, h_g is height above ground, s the swath width, Ω the swath field of view, IFOV the instantaneous field of View, a' and b' the dimensions of the sensor detector size, a_0 the GSD across track, $b_0 = v\Delta t$ the GSD along track, v the platform velocity and Δt the dwell time. Whiskbroom sensors are described in more detail in Annex E.

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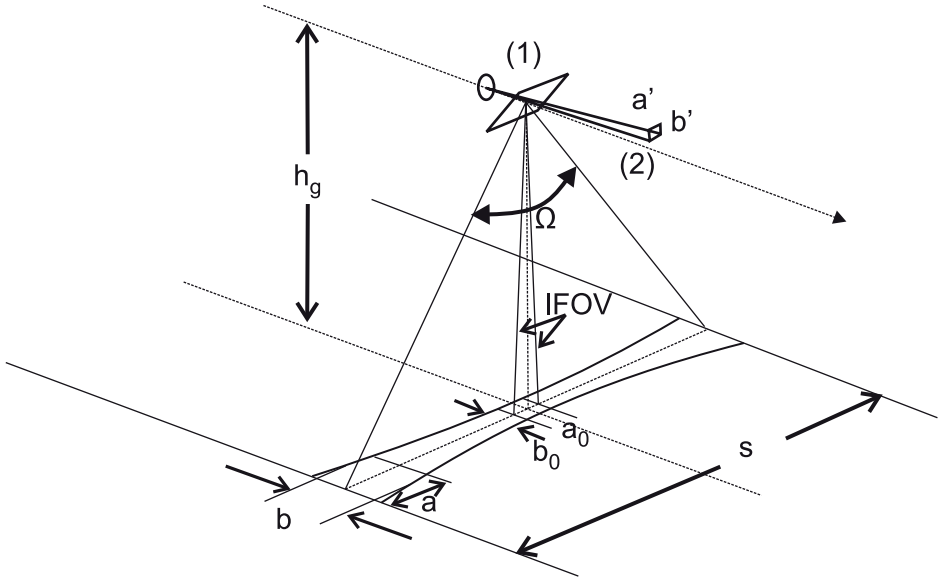

Key

1 optical system

2 focal plane

Figure 5 — Optical layout of a whiskbroom scanning sensor

8.1.5 Synthetic Aperture Radar (SAR)

Remote sensing systems using radar (radio detection and ranging) send radio signals towards an object and measure the intensity and phase of the reflected wave. The time and the phase difference between the sending of the signal and its return provide the distance to the object. With the measurement of the time it takes for a signal transmitted by an antenna to return to that antenna (or, in some cases, a different antenna), as well as the magnitude of the returned signal, as shown in Figure F.2 being combined with the position and attitude of the sensor, the position of a target object can be derived. The intensity of the reflectance allows different types of surfaces to be distinguished.

Synthetic Aperture Radar (SAR) is a kind of radar that uses a series of radar pulses transmitted and received over time from a moving platform to create an image. SAR differs from other kinds of radars, known as Real Aperture Radars (RAR)s, by creating a large virtual antenna, known as the synthetic aperture, that allows tight focusing of the virtual beam in the along-track direction.

In SAR, the size of the antenna is synthetically enlarged by treating a series of returns from a much smaller physical antenna that is moving relative to the target as one long antenna (aperture). The distance the platform moves in synthesizing the antenna is known as the synthetic aperture. By synthesizing a large array, SAR can enjoy the benefits of improved angular resolution that come with large physical antennas without the technical and physical problems associated with them. In fact, much larger synthetic apertures can be formed than would be possible using a real physical antenna. This method improves the geometric resolution of the system considerably. RAR images points along a line perpendicular to the flight track; it takes advantage of the Doppler shift of the reflected radiation to filter out returns from points ahead of or behind that line. SAR uses the Doppler shift together with the return time to determine the position (angle and distance) from which the return was reflected; because of that, it can sum the returns received from any given point over the time in which the physical antenna is moved along the length of the synthetic antenna.

Raw SAR data can be processed into many products, one of which, known as a "detected image", is commonly referred to as a SAR image. SAR geopositioning is primarily dependent upon the accurate measurement of the sensor position and sensor velocity, with acceleration being a secondary factor. SAR geometric sensor models are completely independent of the sensor's pointing attitude. This behaviour is quite different from geopositioning with passive light-sensing systems, such as frame and

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pushbroom sensors, because SAR images or other products are created by processing the radar signal's time and frequency characteristics, rather than physical pointing characteristics. Only the quality of the product (e.g., noise level, dynamic range) is a function of the pointing direction of the antenna, since the magnitude of the returned signal depends upon the amount of energy illuminating the region processed into the image, which is a function of the antenna beam pointing. (This is analogous to a camera with an independently pointed light source, in which the camera can point in any direction, but the quality of the image depends upon where the light is pointing relative to the camera.) Annex F describes SAR imaging in more detail. 8.6.5 describes content that shall be provided in order to geolocate SAR images.

ISO/TS 19101:2008, 7.1.4.1 has discussed the resolution of imagery. The spatial resolution of a SAR system is measured in terms of the system's Impulse Response (IPR). This is the width of the return generated by a small point reflector, which equates to the smallest distance between two point reflectors that can be distinguished as two objects shown in Figure F.1[13]. SAR images are very often oversampled in order to retain as much information as possible. The Nyquist–Shannon Sampling Theorem states that exact reconstruction of a continuous-time baseband signal from its samples is possible if the signal is band limited and the sampling frequency is greater than twice the signal bandwidth.

The minimum sampling rate is sometimes referred to as the *Nyquist Rate* or the *Nyquist Frequency*. This theorem also applies to spatial signals, such as images, and the practical application of this to imaging is that in order to retain all of the information acquired by a sensor (e.g. radar or optical), the image should be sampled at twice the resolution of the signal reaching the sampling device. Other considerations, such as cost, efficiency and value, may result in decisions to sample at lower rates. For SAR, it is common to see sampling rates in the range from the Nyquist Rate to 1/2 the Nyquist Rate, which translates to GSDs of 1/2 the IPR width to the IPR width, respectively. From the standpoint of SAR photogrammetry, the GSD of the pixels is more important than the IPR; although understanding the range and azimuth resolution equations is fundamental to the photogrammetric process.

The spatial resolution in the range direction (i.e. radially away from the antenna) is dependent upon the ability to measure the pulse arrival times. These times can be measured with high accuracy in modern radar systems. When a radar system is used to image the ground, the term *slant range resolution* is used to refer to the resolution in the range direction. Ground range resolution, r_{GR}, refers to the resolution of the radar information projected onto the ground surface, which varies with the grazing angle – the angle between the ground surface and the direction of travel of the radar energy [Formula (F.2)]. Thus, the ground range resolution is always coarser than the slant range resolution, and the ground range resolution is poorer (i.e. decreasing resolvability) at nearer ranges when the platform is at constant height (Figure F.3). This situation is the opposite of the range-to-resolution relationship for optical systems. As the ground range nears zero (i.e. the sensor is pointed nearly straight down), the $cos(\gamma)$ term in Formula (F.2) goes to zero and the range resolution approaches infinity. This explains why radar imaging systems cannot image directly along the ground track of the aircraft, and why they have a near-range limit for practical utility. This is often set to around a 60° grazing angle, at which the ground range resolution is twice the slant range resolution.

RAR systems change the position or pointing of the antenna in order to measure signal returns in different directions. Their resolution in the direction of rotation or translation, known as azimuth resolution, r_A, is dependent upon the width of the beam at the target [Formula (F.3)]. Since the azimuth resolution is inversely proportional to antenna size and proportional to range to the target, long range imaging at even moderate resolution may require an antenna size that exceeds what can be practically built and carried on an aircraft. The invention of SAR resolved this problem by using motion of the radar to synthesize a very large antenna.

SAR systems employ a chirped pulse, which imposes a frequency modulation on each radar pulse. Using this technique, the radar can better distinguish between overlapping pulses [Formula (F.4)]. Chirped pulses are used by many types of radars, not just SARs.

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8.2 Physical Sensor Model approach

8.2.1 Physical Sensor Model introduction

This approach is the most fundamental way of modelling the relationship between image space and object (ground) space coordinates. The PSM uses information on the sensor's properties, attitude and position to mathematically derive the geometric relationship between the location of any pixel in the image and its location in the object (ground). This mathematical description is in the form of equations that relate pixel (line, sample) coordinates to the their corresponding 3D ground coordinates, either geographic (λ, φ, h) or Cartesian (X,Y,Z).

8.2.2 Physical Sensor Model parameters

The mathematical functions describing the PSM contain the most important parameters involved in image acquisition, both

a) internal sensor characteristics (such as focal length, principal point offset, pixel size and distortion coefficients), and

b) external parameters dependent upon the collection platform (such as sensor location in the object space, sensor orientation and collection platform velocity). Whereas the interior parameters are usually independent of time, exterior parameters may or may not be.

For imaging by a passive frame sensor, all pixels in a single frame have one set of EO parameters since they are imaged at the same time. On the other hand, all other sensors involve scanning and therefore the elements of EO are time-dependent functions.

8.2.3 Interior sensor parameters

These parameters pertain exclusively to the sensor and the mode in which it operates. For all passive electro-optical sensors, a lens is used to collect and focus the energy emanating from the object onto the sensing medium. This medium may be film (which is later scanned to convert the image to digital form) or a sensing element such as a CCD. Film and rectangular arrays of sensing elements are used for frame (area recording) imagery. Linear arrays are used for pushbroom imaging, while a single element (or one or a few arrays each with very few elements) is used to sweep across-track in whiskbroom imaging. Interior orientation parameters are listed below:

a) The calibrated focal length of the lens.

b) Lens distortion characteristics. They are in the form of coefficients of polynomials that are specifically derived to fit the distortion curves, both for radial as well as decentring (also sometimes called tangential or asymmetric) distortion.

c) Size and shape of a single detector in the array.

d) Geometric distortion of the image record. This represents film deformation for cameras and array deformations for digital imagery. Usually such distortion is represented by coefficients of a transformation, determined by calibration, using reference points (such as fiducial marks in a frame camera). The most common transformation is the six-parameter affine transformation, which accounts for two translations, two scales, one rotation and a skew.

e) The location x_0, y_0, of the intersection of the optical axis and the image plane, which is usually called the principal point offset.

Items a) through e) constitute a complete list of interior orientation elements that apply to frame imagery. For pushbroom and whiskbroom passive imagery, only subsets that are physically relevant are used. Model formulation for all cases includes the pertinent elements.

For what are termed metric sensors, the interior orientation parameters are usually determined a priori, through laboratory calibration or special field calibration. In some cases, full calibration of the

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sensor prior to the imaging is not possible. In such cases, it is possible to refine the available interior parameters and determine those through a self-calibration.

8.2.4 Exterior sensor/platform parameters

EO parameters pertain to the trajectory of the platform that carries the sensor, and are, in general, dependent on time. For passive optical sensors, an image CRS is established with its origin at the perspective centre, which is physically located at the front node of the lens, the single point through which the bundle of rays from the object being imaged passes. The position of the origin (often called perspective centre for frame images) together with the orientation of this coordinate system with respect to the established ground coordinate system constitutes EO. The position is determined by three coordinates and orientation by three independent parameters, usually a sequence of three angles.

The position of the origin of the SCS shall be described in the simplest case by a set of object space coordinates; the external CRS may be a global geocentric or geodetic CRS or an engineering CRS referenced to a point on the surface of the Earth.

More often, the position of the origin of the SCS is specified in relation to a coordinate system defined for the platform upon which the sensor is mounted. In this case, the position of the origin of the SCS shall be described by an offset vector from the origin of the platform CRS. The position of the origin of the platform CRS shall be specified in relation to the object space CRS.

For a gimbal mounted sensor, a local CRS shall be defined for each stage of the gimbal, with the origin of the CRS for the first stage being located at the point where it is mounted to the platform and the origin for the CRS of each subsequent stage being at its centre of rotation. In this case, the origin of the SCS shall be described by a sequence of offset vectors from the origin of the platform CRS to the origin of the SCS.

Attitude describes the orientation of the internal coordinate system of a body such as a sensor relative to an external CRS. This description may consist of a sequence of angles, each of which describes a rotation of the internal coordinate system around one axis of the external CRS. Generally, ω (roll) is the angle of rotation around the x axis, φ (pitch) the rotation around the y axis, and κ (yaw) the rotation around the z axis. A rotation is positive if it appears clockwise when looking in the positive direction of the axis around which the rotation takes place. The order of rotation shall be specified since the results of a sequence of rotations are not commutative.

Alternatively, attitude may be described by a 3x3 rotation matrix built up by the multiplication of three matrices that consecutively rotate the internal coordinate system around each axis of the external CRS.

As in the case of position, the attitude of a sensor may be described relative to the object space CRS, to the platform CRS, or to the CRS of the final stage of a gimbal mounting.

In photogrammetric applications, the EO information of the sensor at exposure time, either directly from the sensor or derived from the platform, is critical since it provides the parameters included in the collinearity equation.

For pushbroom and whiskbroom sensors, which acquire imagery by scanning the object (terrain), the EO parameters are time-dependent. Each EO element or parameter is determined for a detector at a specific instance of time. This is usually accomplished by a polynomial, fitting to non-time congruent platform EO data but could also be accomplished through interpolating such tabulated data.

The data set may provide the attitude and position information directly or it may contain other information from which attitude and position can be calculated. Two examples are shown.

EXAMPLE 1 Figure 6 shows a geolocation table that contains Date, Time and three columns each for Attitude (ω, φ, κ) and Position (X,Y,Z) for deriving geolocation information for scans.

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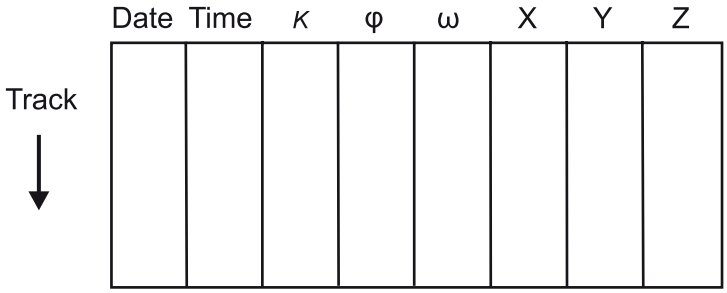

Figure 6 — One-dimensional attitude/position table of geolocation information

EXAMPLE 2 Figure 7 shows an example where multiple sets of attitude and position information are available for an image. The six 2D arrays of Attitude and Position components have been combined into a single 3D array for convenience. Geolocation information may not be needed for every scan; depending upon accuracy requirements, providing it at intervals of several scans may be sufficient.

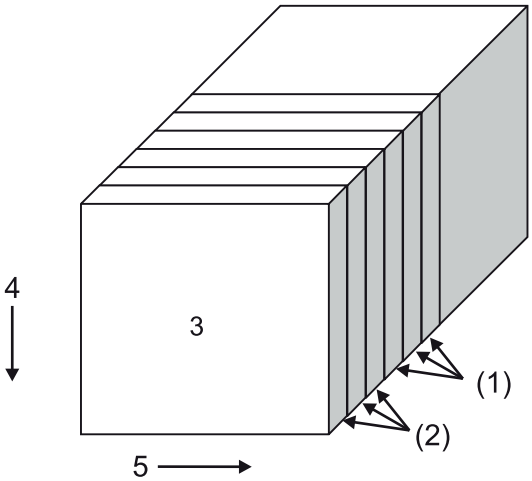

Figure 7 — Geolocation array containing attitude and position planes

The physical arrangement aboard the platform is very important in the proper construction of the mathematical model for the sensor. The sensor may be separated from the GNSS antenna (which provides position) and from the inertial navigation system (INS) (which provides orientation angles). Therefore, the offset vectors from the origin of the platform CRS to the sensor, the GNSS, and the INS are critical to determining the EO of the sensor unless the position and orientation of the sensor are measured directly.

8.2.5 Ground-to-image function

The ground-to-image function is one of the two forms of the fundamental relationship that mathematically expresses the sensor model. The other form is the reverse image-to-ground function that is discussed in 8.2.6. Figure 8 schematically depicts the role of the ground-to-image function, which applies equally to the original physical/geometric sensor model currently under discussion, or the TRM, which will be discussed in 9.2. The inputs to this function are the ground coordinates, either geographic (λ, φ, h) or Cartesian (X,Y,Z), and their statistical quality, as represented by a 3-by-3 covariance matrix, Σ . The output is the pair of image coordinates in the image record corresponding to the object point represented by the ground coordinates. Image coordinates can be either grid (line, sample) coordinates in pixels or Cartesian coordinates (x,y) in linear units such as mm. Also output is the quality of the image coordinates in the form of a 2-by-2 covariance matrix. The construction of the ground-to-image function depends upon the entire set of parameters involved in the imaging event. For a PSM, these are the interior and EO parameters discussed in 8.2.1 to 8.2.4, and their covariance information. A different set of parameters is used in the TRMs discussed in 9.2.

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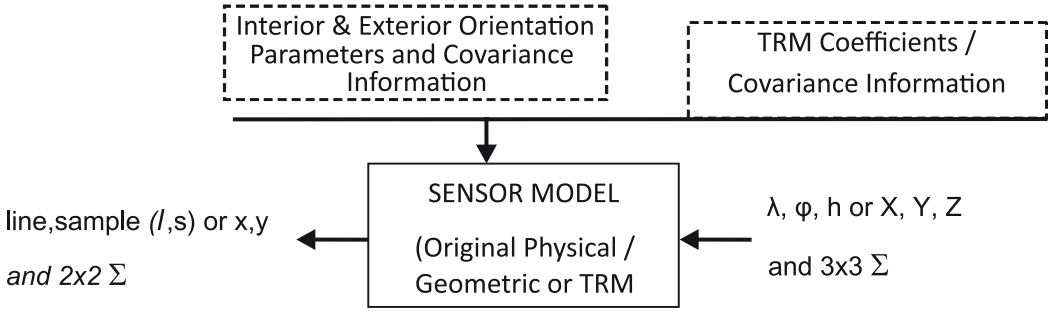

Figure 8 — Ground-to-image function

For a frame image, the ground-to-image function is expressed by two collinearity equations. For fully calibrated cameras, they are:

$$x' = -f\frac{U}{W}$$
$$y' = -f\frac{V}{W} \tag{1}$$

in which

$$\begin{bmatrix} U \\ V \\ W \end{bmatrix} = M \begin{bmatrix} X - X_L \\ Y - Y_L \\ Z - Z_L \end{bmatrix} \tag{2}$$

where

x', y'	are image point coordinates which have been corrected for all systematic errors, including shift to the principal point (x_0,y_0), as the origin;
x_0, y_0, f	are the elements of interior orientation of the calibrated camera; x_0,y_0 are the coordinates of the principal point, and f is the calibrated focal length;
X_L, Y_L, Z_L	are three positional elements of EO in the object (ground) CRS;
M	is the orthogonal matrix representing the sensor orientation, constructed in terms of the other three elements of EO. These elements are usually a set of sequential rotations, ω,φ,κ, , called roll, pitch, and yaw;
X, Y, Z	are ground coordinates of the object point in the object (ground) CRS whose image is given by the coordinates x, y.

If uncalibrated or partially calibrated sensors are used, the collinearity equations are extended to accommodate self-calibration. A pair of equations that include a set of self-calibration parameters is given as follows:

Replace

x', y' by: $x' = \bar{x} + \Delta x \qquad y' = \bar{y} - \Delta y$

in which:

$\bar{x} = x - x_0$ $\bar{y} = y - y_0$ and $r^2 = \bar{x}^2 + \bar{y}^2$ in the following:

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$$\Delta x = \frac{\bar{x}}{f}\Delta f + \bar{x}(k_1 r^2 + k_2 r^4 + k_3 r^6) + p_1(2\bar{x}^2 + r^2) + p_2(2\overline{xy}) + b_1\bar{x} + b_2\bar{y}$$
$$\Delta y = \frac{\bar{y}}{f}\Delta f + \bar{y}(k_1 r^2 + k_2 r^4 + k_3 r^6) + p_1(2\overline{xy}) + p_2(2\bar{y}^2 + r^2) \quad (3)$$

where there are 10 added self-calibration parameters

$x_0, y_0, \Delta f$ is the interior orientation (Δf is a correction to the focal length f, which will also accommodate a uniform scale change);

k_1, k_2, k_3 are the radial lens distortion coefficients;

p_1, p_2 are the decentring lens distortion coefficients;

b_1, b_2 are parameters which collectively accommodate a differential scale in one axis compared to the other, and a skew between the two axes.

8.2.6 Image-to-ground function

For some sensor/sensing systems, the ground-to-image function is mathematically invertible uniquely. Such is the case for calibrated frame imagery, resulting directly in the following image-to-ground transformation.

$$X = X_L + (Z - Z_L)\frac{u}{w}$$
$$Y = Y_L + (Z - Z_L)\frac{v}{w} \quad (4)$$

in which

$$\begin{bmatrix} u \\ v \\ w \end{bmatrix} = M^T \begin{bmatrix} x' \\ y' \\ -f \end{bmatrix} \quad (5)$$

In order to determine (X, Y) of an object point from Formula (4), its third dimension Z (elevation) is required. This is because one cannot recover all three coordinates of an object point from its two image point coordinates. Once the third dimension is lost in the imaging process, it cannot be recovered from a single image. It can, however, be calculated if two or more images of the same object point are used.

For time-dependent imaging systems, such as pushbroom and whiskbroom, the ground-to-image function cannot be directly inverted algebraically as it is for frame imagery. The image-to-ground function is instead derived numerically from the ground-to-image function by an iterative procedure, or as

$$\begin{bmatrix} X - X_L(t) \\ Y - Y_L(t) \\ Z - Z_L(t) \end{bmatrix} = kR(t) \begin{bmatrix} x \\ y \\ z \end{bmatrix} \quad (6)$$

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where

X, Y, Z	are object point coordinates;
$X_L(t), Y_L(t), Z_L(t)$	are coordinates of the perspective centre in the object (ground) CRS. They are continuous functions of time, t;
k	is the scale factor which varies from point to point;
$R(t)$	is a 3-by-3 rotation matrix which brings a framelet (which is usually a single image line for a pushbroom image) coordinate system parallel to the object coordinate system. R is a continuous function of time;
x, y, z	are framelet coordinates of the image point, in the image CRS, corresponding to X, Y, Z.

This image-to-ground form of the collinearity is chosen because time is usually determined by the image line, thus making this a direct, rather than iterative, approach.

Z can be determined if two or more images from different viewing angles are used.

Both the ground-to-image and image-to-ground functions form the basis of the PSM, which allows rigorous exploitation of imagery for precise geopositioning based on well established photogrammetric processes. These two functions, together with error propagation and adjustability, which provide the ability to refine or upgrade the sensor parameters, make up the four basic elements of a PSM.

8.2.7 Error propagation

Most, if not all, variables involved in sensor models, whether known a priori or estimated, are random (or stochastic) variables. This means that variances and covariances are associated with the variables. When a sensor model is applied, a set of unknown quantities is calculated from known values. The operation of determining the covariances of the calculated quantities from the covariances of the known input values is called error propagation. Rigorous error propagation associated with geopositioning is as important as the determination of the Earth coordinates themselves.

8.2.8 Adjustable model parameters

Frequently the values of the sensor parameters available in the metadata are not sufficiently accurate to lead to quality geopositioning. Photogrammetric techniques exist that allow refinement of some or all of those parameters. The parameters selected for this refinement are called adjustable model parameters.

8.3 Quality associated with Physical Sensor Models

Quality information for PSMs shall be provided using the appropriate quality measures specified in ISO 19157:2013. The quality parameters associated with PSMs fall into two categories: interior, which pertain predominantly to the sensor design, and exterior, which reflect more the properties of the collection platform trajectory than those of the sensor. Variances and covariances should be provided for the interior parameters since any or all of them may be carried as adjustable parameters. The primary source of error in object expositions comes from the exterior parameters. The covariance matrix of the EO elements is:

$$\Sigma_{EO} = \begin{bmatrix} \sigma^2_{X_L} & \sigma_{X_L Y_L} & \sigma_{X_L Z_L} & \sigma_{X_L \omega} & \sigma_{X_L \varphi} & \sigma_{X_L \kappa} \\ & \sigma^2_{Y_L} & \sigma_{Y_L Z_L} & \sigma_{Y_L \omega} & \sigma_{Y_L \varphi} & \sigma_{Y_L \kappa} \\ & & \sigma^2_{Z_L} & \sigma_{Z_L \omega} & \sigma_{Z_L \varphi} & \sigma_{Z_L \kappa} \\ & & & \sigma^2_{\omega} & \sigma_{\omega\varphi} & \sigma_{\omega\kappa} \\ & \text{symmetric} & & & \sigma^2_{\varphi} & \sigma_{\varphi\kappa} \\ & & & & & \sigma^2_{\kappa} \end{bmatrix} \tag{7}$$

where

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$\sum_{EO}$	is the covariance matrix of the EO elements;
$\sigma^2 i$	are variances;
σ_{ij}	are covariances;
X_L, Y_L, Z_L	is the position of the perspective centre;
ω, φ, κ	are the angles that describe the attitude of the sensor.

The diagonal elements of the square symmetric non-singular matrix, $\sum_{EO}$ are the variances of the position (X_L, Y_L, Z_L) and orientation (ω, φ, κ) of the sensor. The off-diagonal elements are the covariances among the six orientation elements. Covariance matrices, as described by Formula (7), shall be provided with all images from passive sensors for which geolocation information is provided as a PSM.

Covariances will always exist if the image has been processed through either single image resection or as part of multi-image triangulation. For an unprocessed image, $\sum_{EO}$ may simply be a diagonal matrix containing variances, with all off-diagonal elements being zero. On the other hand, for a processed image, $\sum_{EO}$ will be a full matrix. In fact, for two processed images, i, j, their total covariance matrix, $\sum_{EO_T}$ will be a 12-by-12 symmetric non-singular matrix of the form:

$$\sum_{EO\ T} = \begin{bmatrix} \sum_{EO\,i} & \sum_{EO\,ij} \\ \sum_{EO\,ij}^{T} & \sum_{EO\,j} \end{bmatrix} \tag{8}$$

where

$\sum_{EO_T}$	is the total covariance matrix for two images;
$\sum_{EOi}$	is the covariance matrix for image i;
$\sum_{EOj}$	is the covariance matrix for image j;
$\sum_{EOij}$	is the covariance matrix between the two images;
$\sum_{EOij}^{T}$	is the transpose of the covariance matrix between the two images.

For a pair of correlated images, the matrix in Formula (8) shall be provided in order to calculate quality measures associated with PSMs.

8.4 Physical Sensor Model metadata

8.4.1 General

The sensor interior and exterior parameters and their associated quality information shall be supplied to enable the user to construct the sensor model for use in the geolocation of object features. The remainder of 8.4 specifies the content of that information about the sensor needed to georeference the data.

8.4.1 provides an overview of the schema for PSM metadata. The information needed to determine the location of the platform on which the sensor is located and the position and motion of the sensor is specified in 8.5. The information needed to describe the internal properties of the sensor and detector system is specified in 8.6. It provides specific information for frame, scanning and radar sensors.

The content specified in this clause provides components that can be used to construct sensor models for many of the different systems used for remote sensing, such as those described in 8.1. It can apply to radiation measurements at many wavelengths and to sound waves. It can apply to sensors of varying degrees of complexity. Separate content for radar systems may apply to echoing systems in general. Many satellite systems use scanning sensors. Location might be determined through time and the satellite orbit. The classes for optics are used to describe the optical systems and the scans. Frame camera photogrammetry is generally from airborne platforms, and it uses the optical system and possibly the distortion classes. Radar is an echo system used from airborne or satellite platforms. For each kind of sensor, a model can be constructed using the UML models in this clause.

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8.4.2 Overview of the Physical Sensor Model schema

Figure 9 illustrates the top of the schema for PSMs. SD_PlatformParameters and its subordinate elements are specified in 8.5, as is SD_PositionAndOrientation; the sensor specific elements of and subordinate to SD_SensorParameters are specified in 8.6. The classes shown in Figure 9, their attributes and their associations shall be used as specified in the data dictionary of B.2.3.1.

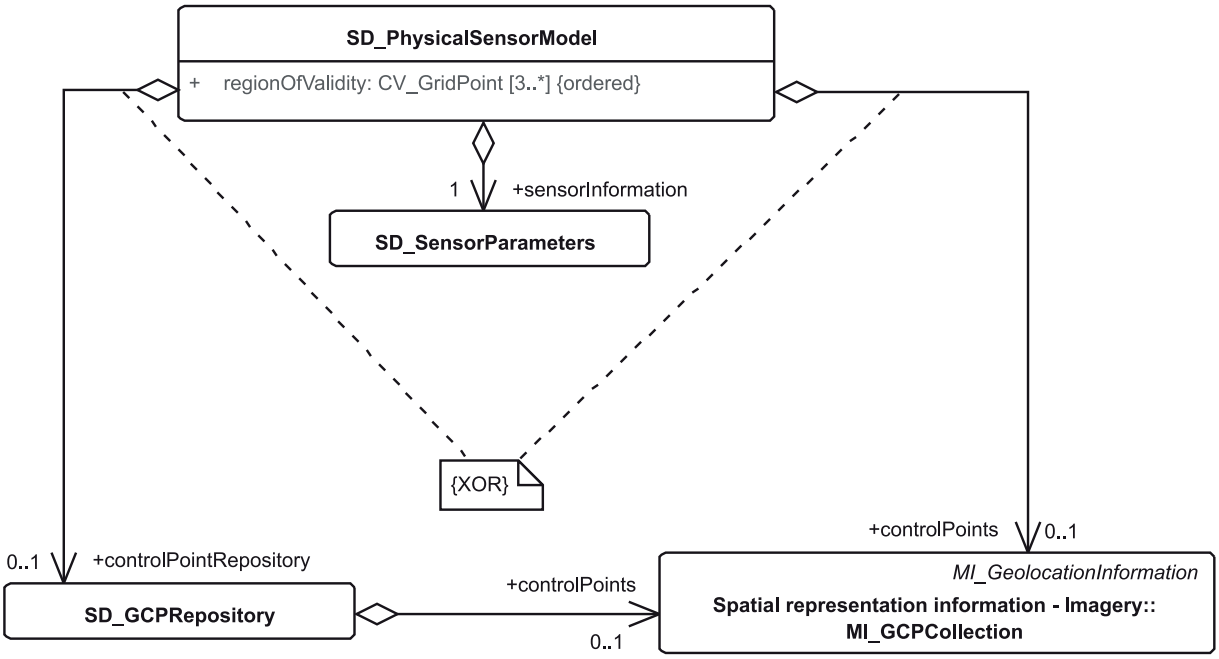

Figure 9 — Overall view of Physical Sensor Model parameters

8.5 Location and orientation

8.5.1 Overview

The location information specified in 8.5 may be used to describe spatial relationships among the components of a sensor, between sensor and platform, between a sensor and the Earth, and between a platform and the Earth. The relative spatial positions and attitudes of the two objects involved shall be described in terms of two different CRSs (Annex C). Each of the two objects has its own CRS. That of the object to be located is the internal CRS, and that of the object on which it is located is called the external CRS. In the process of location, the axes of the internal CRS are defined in terms of the external CRS. The coordinate and location information is independent of any specific sensor class.

In the simplest case, the location of a sensor CRS is given directly relative to a ground CRS. In other cases, a series of transformations, from the ground to the platform, from the platform to the sensor and finally from the sensor to the detector are used. The location of a sensor relative to a platform is called the mounting of the sensor.

If the platform is airborne, land based or waterborne, its location is determined by the platform's internal flight/tracking/cruising control system or from the GNSS. In spaceborne applications, the position is often derived from the platform orbit. For this reason, the satellite ephemeris data are a subclass of the location model.

Some applications determine platform position by interpolating between known positions along the track so this document also specifies velocity and acceleration attributes.

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8.5.2 Position

The position vector in 3D space defines the position of a remote sensing platform or a sensor at a given time. It is measured relative to a CRS such as a Cartesian system or the geographic system (latitude, longitude, altitude).

Position information shall be provided as shown in the UML diagram Figure 10. The classes shown in Figure 10, their attributes and their associations shall be used as specified in the data dictionary of B.2.3.2.

If the platform is airborne, land based, or waterborne, its position is determined by the platform's internal flight/tracking/cruising control system or from the GNSS. That information is represented by the class SD_EarthMeasuredLocation

If the platform is a spacecraft, its position can be determined from its orbital characteristics. An orbit can be described using the Keplerian elements (C.2.2.5 to C.2.2.7).

The spacecraft's orbital tracking data are received by ground stations and are used to determine the platform's instantaneous position and velocity.

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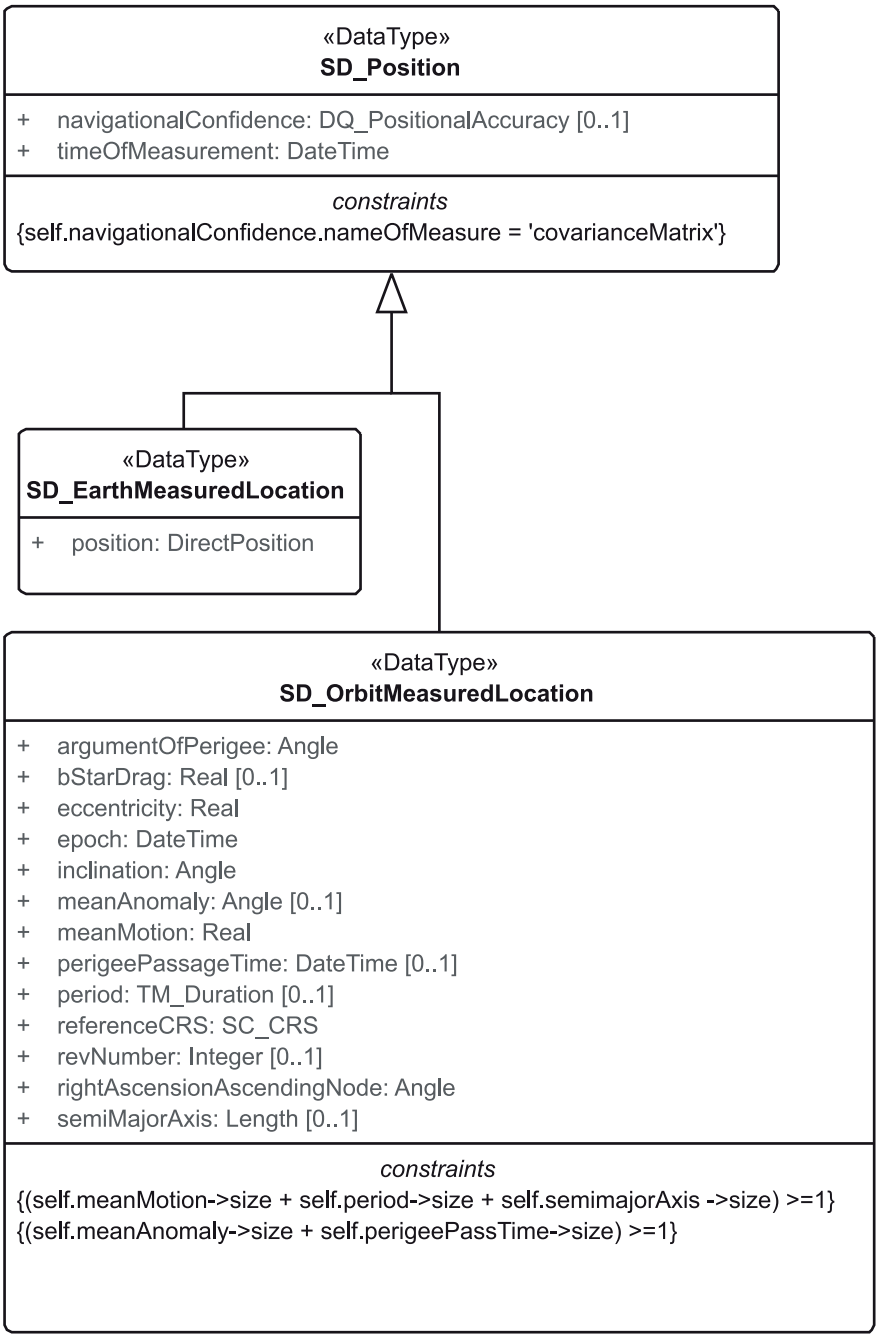

Figure 10 — SD_Position

8.5.3 Attitude

Attitude (Figure 11) describes the orientation of one CRS with respect to another. It does this using either a set of rotation angles, one for each axis (SD_AngleAttitude), or using a rotation matrix (SD_MatrixAttitude). See 8.2.4 and Annex C for more detailed discussion. Attitude information shall be provided using the classes shown in Figure 11 and their attributes as further specified in B.2.3.3 and B.2.5.4.

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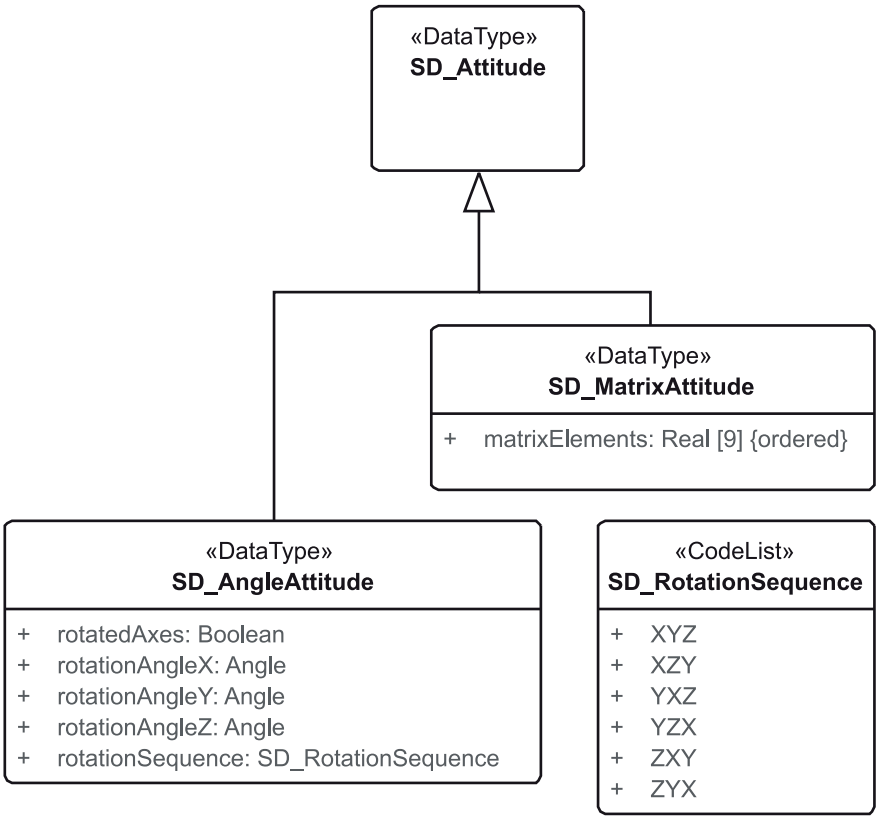

Figure 11 — SD_Attitude

8.5.4 Dynamics

The class SD_Dynamics (Figure 12) provides a set of elements for describing the rates at which elements of position and attitude change over time. The classes shown in Figure 12, their attributes and their associations shall be used as specified in the data dictionary of B.2.3.4.

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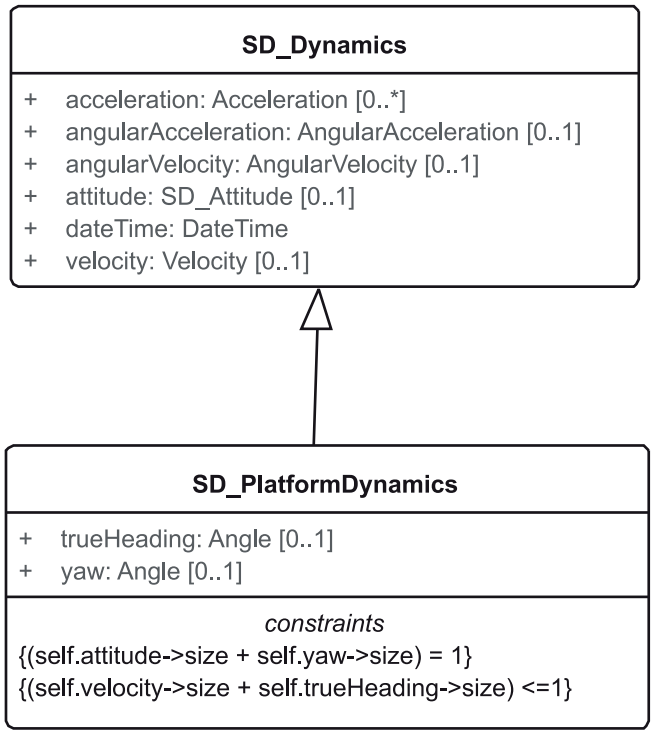

Figure 12 — SD_Dynamics

8.5.5 Position and orientation of a sensor relative to the platform

The class SD_PositionAndOrientation (Figure 13) provides a mechanism for specifying the relative positions and orientations of the components of the platform/sensor system. In the simplest case, the position and orientation of the sensor are described directly with respect to an earth-fixed geodetic or engineering CRS; in this case, the associations terminating in the role names 'platform' and 'mountingObject' shall both be empty. The other simple case is that in which the sensor is mounted directly on the platform. Its position and orientation are described in terms of the platform CRS. In this case, the multiplicity of the role name 'platform' shall be one, while that of the role name 'mountingObject' shall be zero.

However, sensors are often mounted on a series of one or more gimbals or other movable devices. More than one instance of SD_PositionAndOrientation will be needed to describe this situation. Starting from the sensor, there shall be an instance of SD_PositionAndOrientation for each object in the series, ending with the object that is attached directly to the platform. For every instance of SD_PositionAndOrientation except the last, the multiplicity of 'mountingObject' shall be one and that of 'platform' shall be zero. For the instance that describes the object mounted directly to the platform the reverse shall be true: the multiplicity for 'platform' shall be one and that of 'mountingObject' shall be zero. See C.3 for a more detailed discussion of relative orientation. The classes shown in Figure 13, their attributes and their associations shall be used as specified in the data dictionary of B.2.3.5.

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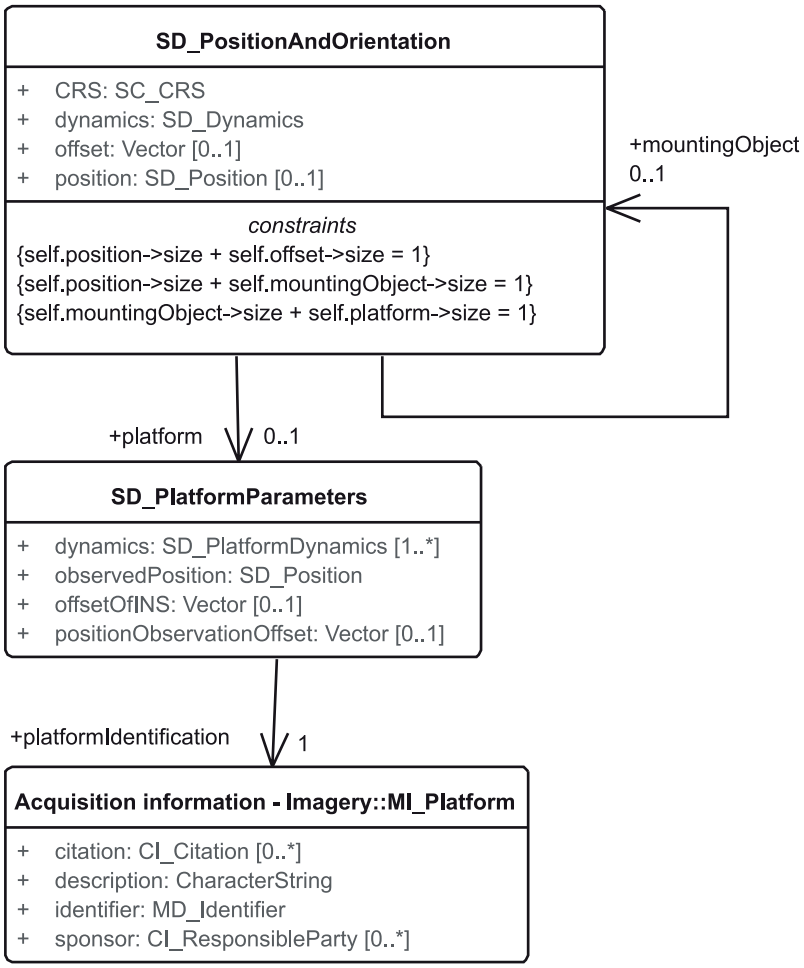

Figure 13 — SD_PositionAndOrientation

8.6 Sensor parameters

8.6.1 SD_SensorParameters

The class SD_SensorParameters represents information about the sensor itself, including its position and orientation relative to the platform (offsetAndOrientation) and its internal characteristics. In addition to its attributes, it aggregates another four classes that describe specific aspects of the sensor. The classes shown in Figure 14, their attributes and their associations shall be used as specified in the data dictionary of B.2.3.6 and B.2.5.2.

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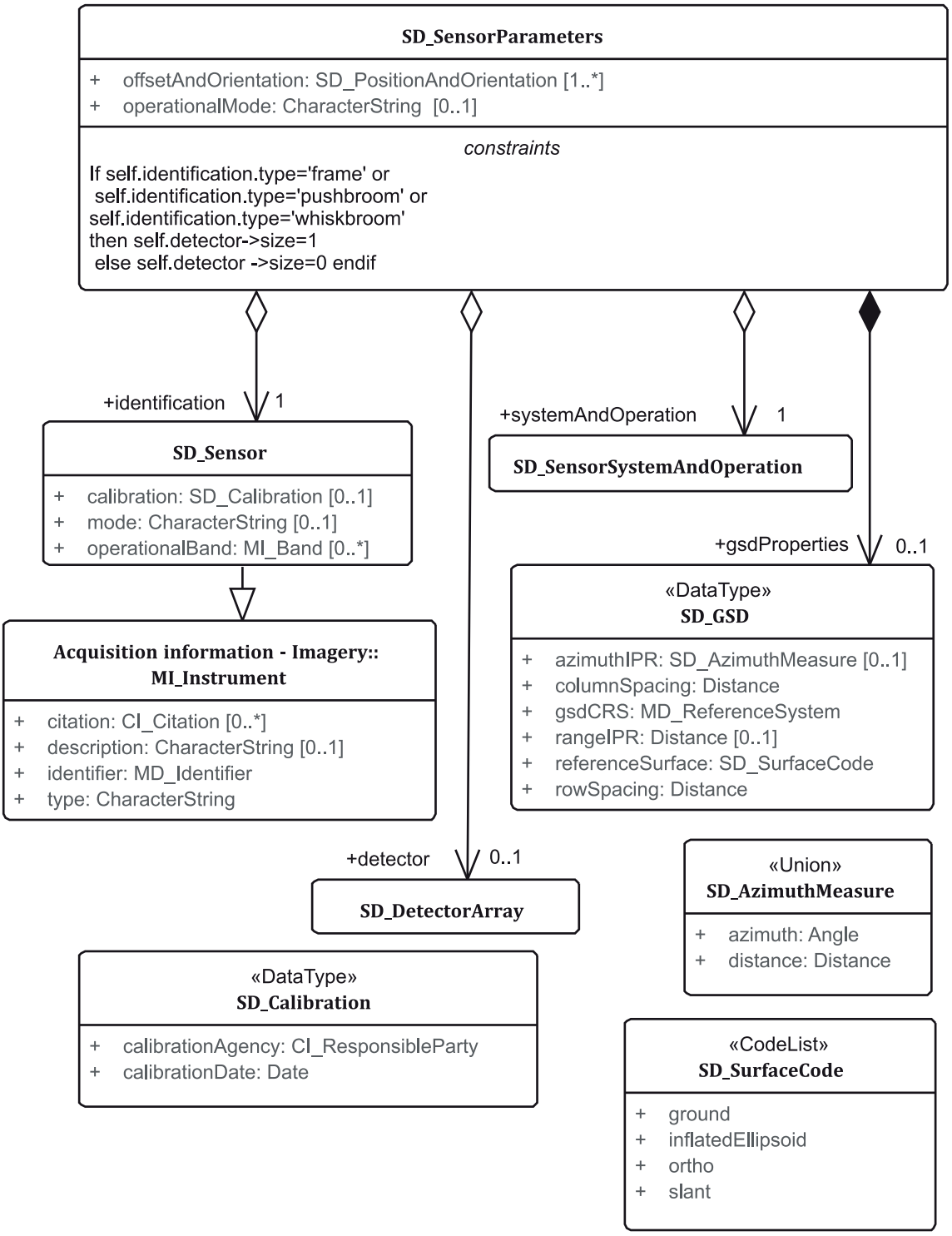

Figure 14 — SD_SensorParameters

8.6.2 Detector array

The class SD_DetectorArray (Figure 15) describes the geometry of the set of detectors used to collect the image values. The attribute numberOfDimensions indicates whether the array is one- or 2D. The attribute arrayOrigin specifies the position relative to the internal CRS of the sensor of the centre of a detector at one of the corners of the array. The attribute arrayDimensions provides the name and of each dimension and its size, which is the number of detectors along that dimension. The attribute offsetVectors describes the orientation of each axis (i.e. dimension) of the array. The magnitude of each

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vector specifies the spacing between detectors in that direction. The values of the offsetVectors shall be ordered such that each corresponds to the appropriate dimension in the sequence of arrayDimensions. The attribute detectorSize specifies the magnitude of each dimension of a detector; its values are also ordered such that each corresponds to the appropriate dimension in the sequence of arrayDimensions. The attribute detectorShape specifies the shape of each detector. The optional attribute distortion describes any known distortions from the geometry described by the other attributes of the class. The classes shown in Figure 15, their attributes and their associations shall be used as specified in the data dictionary of B.2.3.7 and B.2.5.1.

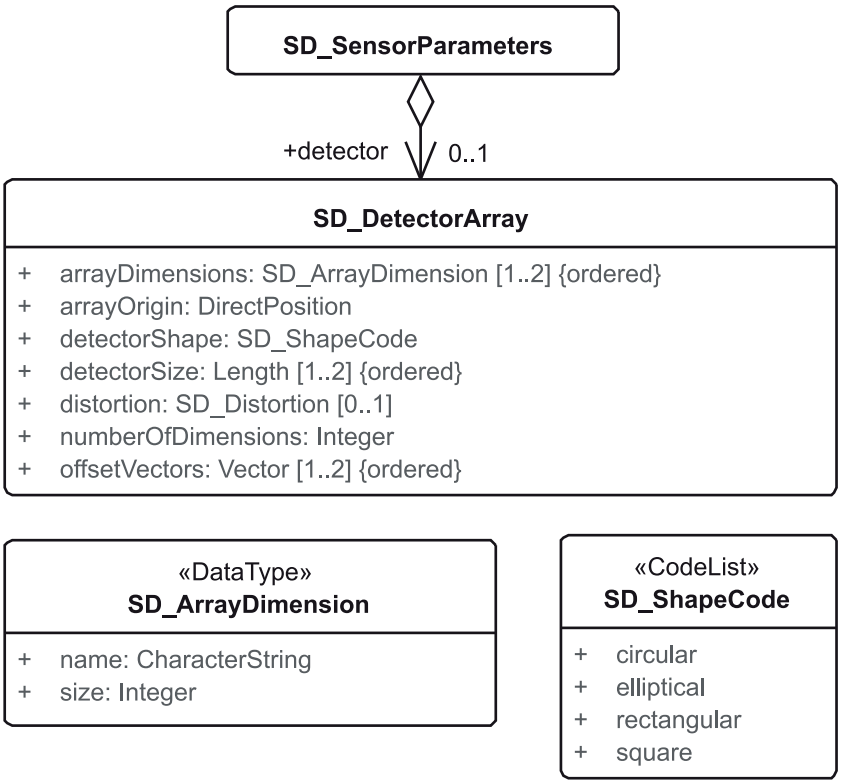

Figure 15 — SD_DetectorArray

8.6.3 Sensor system and operation

The SD_SensorSystemAndOperation class (Figure 16) describes the properties and operational mechanics of the sensor system. Two subclasses are defined based on the wavelength on which the sensor works: SD_Optics and SD_Microwave. The classes shown in Figure 16, their attributes and their associations shall be used as specified in the data dictionary of B.2.3.8 and B. 2.5.3.

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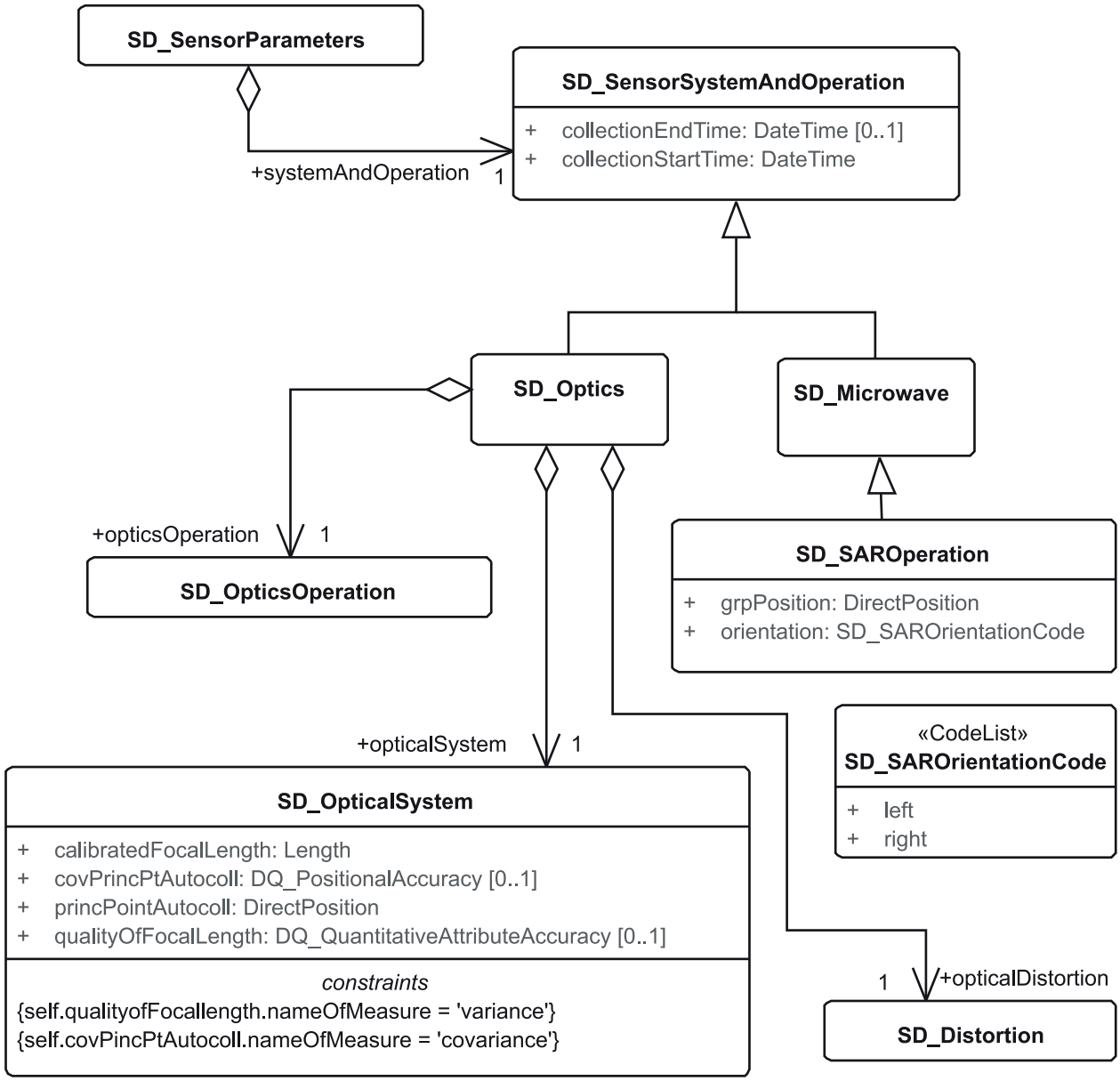

Figure 16 — SD_SensorSystemAndOperation

8.6.4 SD_OpticsOperation

Information on the optical properties and operation of the optical system shall be provided as shown in the UML model of Figure 17. The classes shown in Figure 17, their attributes and their associations shall be used as specified in the data dictionary of B.2.3.9.

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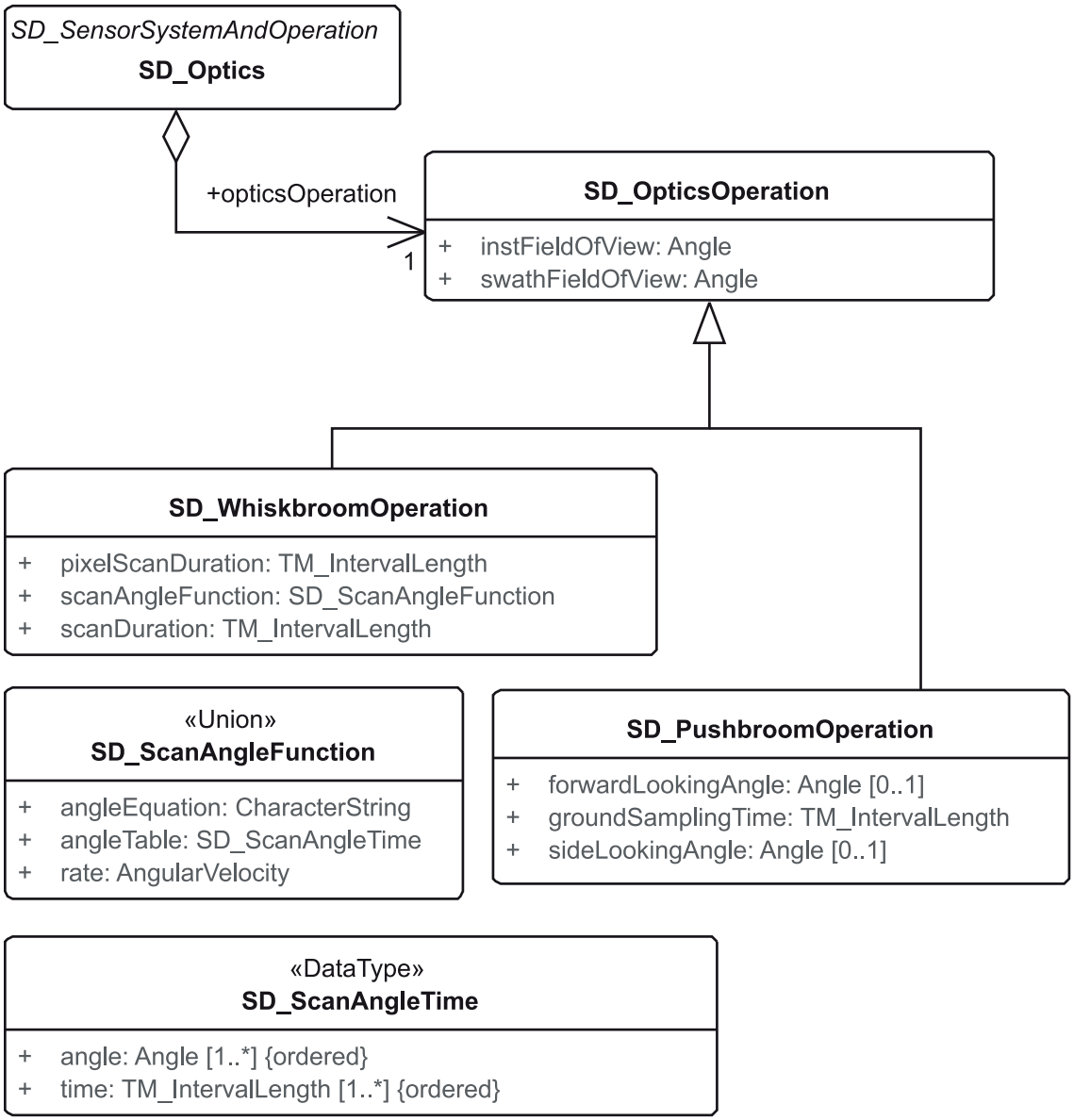

Figure 17 — SD_OpticsOperation

8.6.5 Distortion correction

The class SD_Distortion provides information on different types of distortion in either the optical system (8.2.5) or the detector array (8.6.2). This information shall be provided as shown in the UML model of Figure 18. The classes shown in Figure 18, their attributes and their associations shall be used as specified in the data dictionary of B.2.3.10.

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