PhenoHDF5 : A data structure for plant phenotyping measurements based on the HDF5 format

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Part A: Definition of the storage format for sensor raw data based on HDF5

- ## Purpose of the document

This document proposes and presents the implementation of a single recording format to store all raw data from a multi-sensor phenotyping system.

- ## List of Modifications

Date	Version	Subject	Modified by
15/03/2024	1.26	Addition of the "Crop" attribute in the "Trial" group. Addition of the "Operator" attribute in the "Session" group. Addition of the "FormatName" attribute in the "FileInformation" group Renaming of the "SpectralIndiceX" group to "SpectralSensorX" for more consistency. Renaming of the "Positioning" group to "PositioningX", allowing the storage of several positioning sources if needed. Addition of the "GeometricSensorAttributes" list of attributes to the "PositioningX" group. Addition of the "Tricam" sensor group. Addition of a camera dataset format (DataFormatId 21)	S. Thomas
05/10/2023	1.25	Translation of the present document into English Addition of the conventions used for the different sensor geometric frames. Addition of the "Scanner3DX" group and associated dataset format (DataFormatId 16). Addition of the "SpectralIndiceX" group and associated dataset format (DataFormatId 17). Addition of calibration coefficients as new attributes in the "ThermalCameraX" group. Addition of a new dataset format for those sensors (DataFormatId 20).	S. Thomas

		Renaming of the "EnvironmentalConditions" group to "MeteorologicalSensorX". This group is no longer linked to the "HeadX" group, but directly to the "VectorX" group. Description of two new dataset formats for those sensors (DataFormatId 18 and 19). Addition of the "UTF-8" flag for attributes of "string" type. Removal of the "FormatVersionId" in the "Vector" group attributes : no longer used. Replacement of the term "Scenario" with "Mission".	
15/02/2023	1.24	In the camera group ("CameraX") attributes, replacement of the "BayerGrid" attribute with "PixelFormat" to take into account standard formats (GenIcam). Deletion of the "LensAngularAperture" attribute and replacement with the "PixelSize" attribute for sensor pixel size. Addition of "Width" and "Height" fields for sensor dimensions in pixels. In the thermal camera group ("ThermalCameraX") attributes, deletion of the "LensAngularAperture" attribute and replacement with the "PixelSize" attribute for the size of a sensor pixel. Addition of "Width" and "Height" attributes for sensor dimensions in pixels. In the spectroradiometer group ("SpectrometerX") attributes, addition of the "AngularAperture" attribute to fill in the fiber view attribute. Modification of the "Scenario" dataset description. Update of the "ARVALIS" logo.	S. Thomas
09/02/2022	1.23	Addition in the present document of the content of the specification of sensor raw data frames, formerly referenced as "RF3." The two original documents are now divided into parts A and B. Removal of reference to RF3.	S. Thomas
2/12/2021	1.22	Addition of the "ThermalCameraX" group	R. Reignier
05/03/2019	1.21	Change of terminology of the "TrialInformation" attributes to match the terminology used in PHIS. Addition of "URI" attributes for experimentation equipment and sensors.	S. Thomas
05/10/2018	1.20	Addition of a "LensAngularAperture" attribute in the "Camera" group. Reversal of the "Pitch" and "Roll" definitions, overlooked when the geometric reference frame was changed. Addition of a diagram with sign conventions for rotations.	S. Thomas
19/07/2018	1.19	Replacement of the "MicroPlotId" type form "unsigned int" with "string."	S. Thomas
24/04/2017	1.18	Addition of the "HeadId" attribute in the "Measurement" group, necessary to link with sensors described in the "Head" groups. Replacement of "PlotId" and "PlotOrientation" with "MicroPlotId" and "MicroPlotOrientation."	S. Thomas

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15/02/2017	1.17	Modification of structure and clarification of some concepts to make the format more standard in relation to the various known acquisition systems and operational practices.	S. Thomas
08/02/2107	1.16	Modification of some terminology. Addition of the "Head" group and the "StaticTransforms" dataset following integration of the first systems by Robopec.	S. Thomas
13/12/2016	1.15	Restoration of the sensor position and angle information, deleted by mistake in the previous release.	S. Thomas
03/05/2016	1.14	Factoring of attributes common to all sensors and creation of generic "SensorX" groups. Specificities of each sensor are detailed in "Sensor" subgroups. Addition of an "ExtractionData" group to take into account extraction features at the microplot scale, in case of UAV for instance.	S. Thomas
25/04/2016	1.13	Change of descriptive attributes for the auxiliary measurement heads.	S. Thomas
22/03/2016	1.12	Change of the data hierarchy in the "Plot" group: one or more "Vehicles" groups are indicated inside, and for each, related measurements are indicated in "Measurements" subgroups. Replacement of "Multispectrum" with "MultispectralCamera," which is more suitable.	S. Thomas
03/09/2015	1.11	Modification of the "Time" attribute in the "Measurement" group because it was not suitable originally (use of microseconds in particular).	S. Thomas
31/08/2015	1.10	Addition of "MainHeadSerialNb" and "AuxiliaryHeadSerialNb" attributes	S. Thomas
25/08/2015	1.9	Addition of the "TrialId" attribute in the "TrialInformation" group.	S. Thomas
19/08/2015	1.8	Relocation of software version and raw data frame version information into the "Vehicle" group. Relocation of the "Vehicle" and "AuxiliaryHead" groups, as well as "Log" and "Scenario" datasets into the "Plot" group to manage multi-acquisition systems on the same experimental platform, such as PHENOFIELD. Replacement of the "VersionInformation" and "DataInformation" groups with "FileInformation" and "TrialInformation" respectively.	S. Thomas
12/08/2015	1.7	Change of the "AuxiliaryHead" type from dataset to group. Addition of the "AuxiliaryHeadId" attribute in the group.	S. Thomas
10/07/2015	1.6	Addition of the "Vehicle" subgroup and the "AuxiliaryHead" dataset. Addition of an ID for identifying the sensor geometric reference frame in the "Sensor" group.	S. Thomas
09/07/2015	1.5	Addition of a "SensorId" attribute for each sensor to help identify their position on the acquisition system.	S. Thomas

		Addition of a "Data" dataset for the "ManualSamples" group.	
07/07/2015	1.4	Replacement of "EquipmentId" and "EquipmentSerialNb" attributes for sensors with "SensorModel" and "SensorSerialNb" respectively. Addition of the "SensorType" and "SensorManufacturer" attributes. Addition of a "SilenaId" attribute in the "Plot" group.	S. Thomas
06/07/2015	1.3	Change of "EquipmentId" and "EquipmentSerialNb" types from "unsigned int" to "string."	S. Thomas
05/06/2015	1.2	Addition of the "BayerGrid" attribute in the "Camera" group.	S. Thomas
19/05/2015	1.1	Addition of the "MultiSpectrum" and "ManualSamples" groups.	S. Thomas
17/01/2014	1.0	Creation	S. Thomas

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2   Context

Obtaining plant physiological characteristics by processing data from multiple sensors (cameras, LiDAR, spectroradiometers, anemometers, GPS, accelerometers, etc.) first requires the painstaking task of gathering and extracting the data. These data are traditionally stored in files of various formats, in different directories, and often require auxiliary data (GPS, weather, etc.), also stored in separate files, to be usable.

In order to integrate this preprocessing directly into the acquisition systems, the present document proposes and describes a single data file format, based on HDF5 technology, offering a way to combine all the data acquired by all the various sensors required on the same agricultural plot and providing an autonomous source for processing algorithms, as well as efficient data availability, by using sustainable and scalable write and read routines.

3   Terminology

The following terminology has been chosen to describe the context of phenotyping sensor data acquired in the field:

- *Campaign*: Year of harvest.
- *Place*: Name of locality.
- *Field*: Name of the field or plot where the data were acquired.
- *Experiment*: Name of the experimental setup.
- *Vector*: Equipment embedding one or more acquisition *Heads*.
- *Head:* Device embedding the sensors.
- *Sensor*: Any kind of sensor used for collecting phenotyping data. A human may be considered as a particular *Sensor*, possibly resulting in data to be stored as well.
- *Mission*: Set of actions to be performed on an *Experiment*: sensor settings, number frequency or places where acquisitions have to be made, path to follow in the field, etc.
- *Session*: The data acquired and associated metadata at a given date, with a given *Vector* in a given configuration (sensors, settings, geometry), for a given *Experiment* in a given *Campaign*. The *Session* results from the execution of a *Mission*.
- *MicroPlot*: ID of the microplot in which data were acquired for a given *Experiment*.
- *Measurement*: Set of sensor data acquired in a given *Microplot*, for a given *Session*, at a given time. Makes it possible to aggregate several acquisitions in the same *Microplot* for the same *Session* (for instance, one at the beginning of the session and another at the end).

Throughout the document, the following terms will be used to designate data types with related definitions.

- **char**: 8-bit signed integer
- **byte / unsigned char**: 8-bit unsigned integer
- **unsigned short**: 16-bit unsigned integer
- **short**: 16-bit signed integer
- **unsigned int**: 32-bit unsigned integer
- **int**: 32-bit signed integer
- **unsigned int64 / unsigned long**: 64-bit unsigned integer
- **int64**: - 64-bit signed integer
- **float**: IEEE 754 32-bit single precision
- **double**: IEEE 754 64-bit double precision
- **string:** array of UTF-8 characters

The terminology of the objects that will be used to describe the data frames and file structure is inherited from the HDF5 format definition:

- **Group** (may be seen as a directory in a filesystem)
- **Dataset** (may be seen as a file in a filesystem)
- **Attribute** (may be seen as properties of a group or dataset**)**

4   Reference documents

- RD1: HDF5 User Guide:

https://portal.hdfgroup.org/display/HDF5/HDF5+User+Guides

- RD2: HDF5 Reference Manual:

https://portal.hdfgroup.org/display/HDF5/Libraries+and+Tools+Reference

- RD3: ROS conventional geometric frames for some sensors (cameras, LiDARs):

https://docs.ros.org/en/melodic/api/sensor_msgs/html/index-msg.html

5   Geometric conventions

The geometric conventions used in this format are as follow:

5.1.1   Global geometric reference frame:

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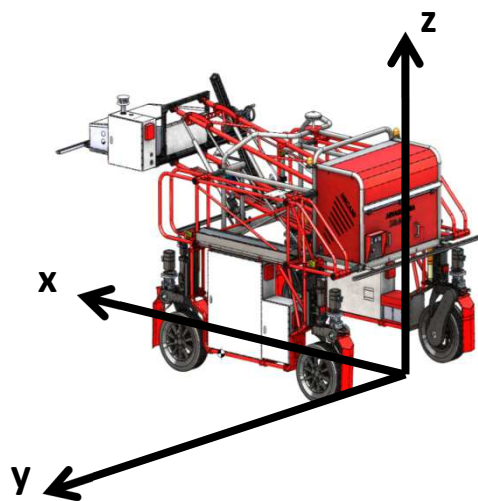
5.1.2 Geometric reference frame for cameras:
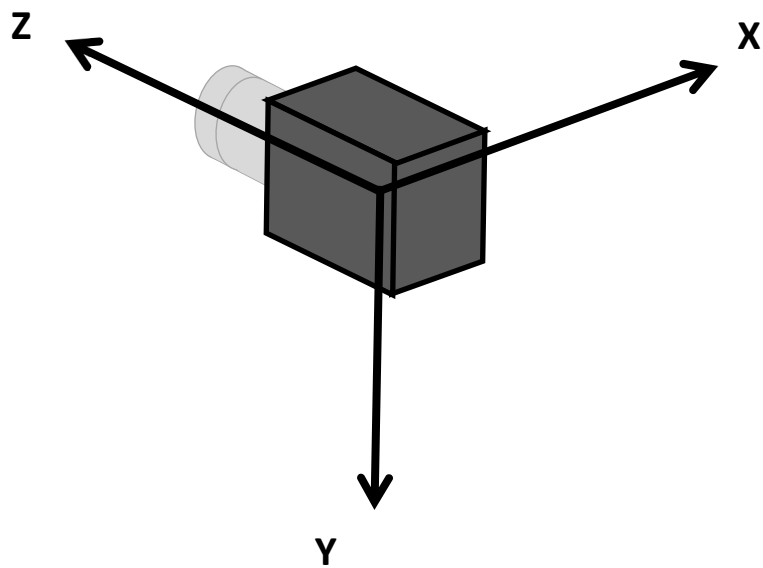
5.1.3 Geometric reference frame for LiDARs:
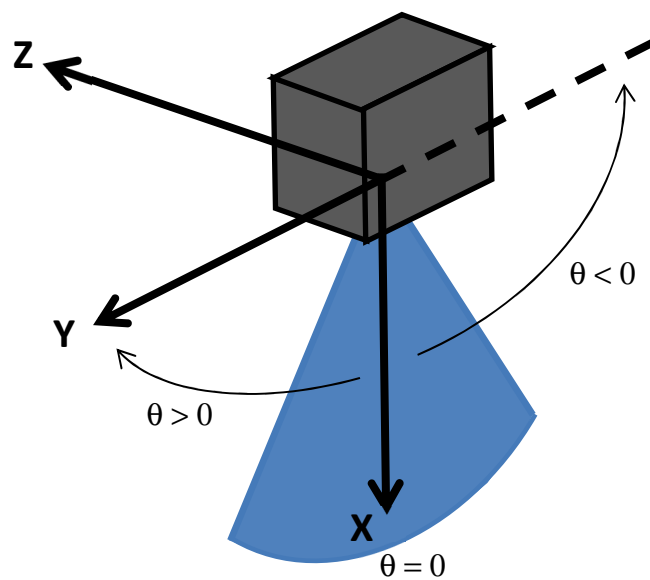
5.1.4 Geometric reference frame for spectroradiometers:
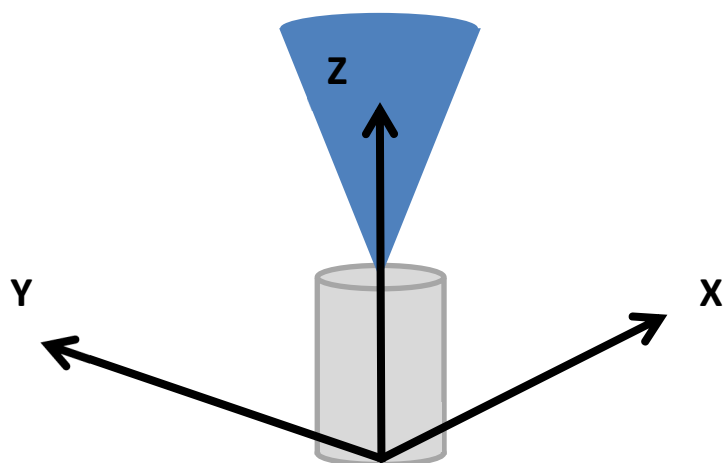
5.1.5 Description of microplot geometric elements:
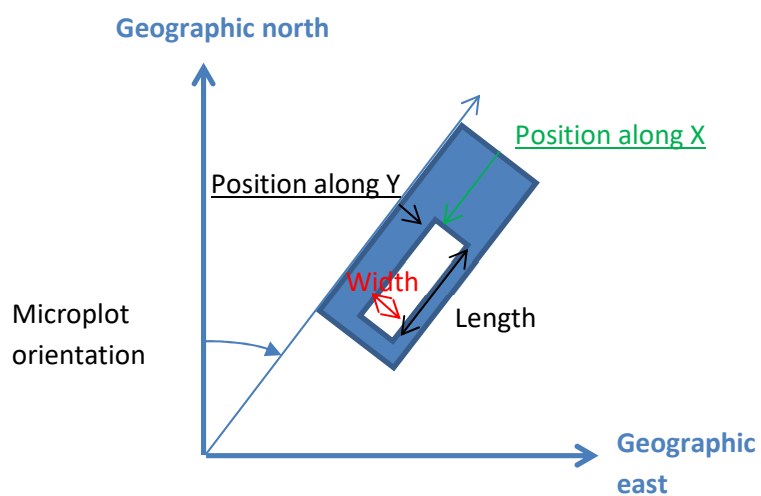
6   Organization of data

This chapter will describe how a file containing phenotyping sensor data was devised and developed.

The proposed format provides a non-ambiguous way to store phenotyping data, all the sensor data acquired on a single *Microplot* on a single date, as well as all the data related to an *Experiment*, enabling processing of the data from a single container.

This is how data may be stored during an acquisition process: a new file is created when entering a new *Microplot*, the data acquired in the Microplot are stored in the file in keeping with the present format, and the file is written and closed when exiting the *Microplot*.

For other purposes (archiving, transfer of a single big file rather than lots of small individual files, etc.) or to operate the acquisition system differently, it may also include the possibility of storing several *Microplot*s of a *Session* and/or several *Session*s without having to change the global structure or design of the file.

The general structure of the data is as follows:

- Once:

  The information related to the version of the present document (*FileInformation*) and the information related to the *Experiment* for which the data are acquired (*TrialInformation*).

- For each *Session*:

  All the data acquired on the *Microplot*(s) and the description of the sensors (settings, positions and angles) embedded on the *Vector.*
  One *Session* is related to one *Vector*.
  Several *Sessions* may be stored in one file.

  - For each Microplot:
    - For each *Measurement*:
      - For each *Sensor:*
        - The acquired data (dataset *Data*)
        - Optional calibration data

  - For the *Vector*:
    - For each *Head*:
      - For each *Sensor*:
        - The settings and positional information
        - The optional calibration data

The following tree describes the content of a generic file.

The red parts represent the mandatory elements to be found in an atomic file for data acquired in one *Session*, on one *Microplot*, once with a single *Sensor* system.

The black parts represent the data that may be found regarding the context. For each object (*Session*, *Microplot*, *Measurement*, *Sensor*, *Vector*, *Head*), X takes any value between 1 and the number of instances of the considered object so that each instance is uniquely defined.

"Sensor" is a generic term for *"Camera"*, *"LiDAR"*, etc. This term does not appear literally in in file.

```
Filename.h5
├── Metadata
│       ├── FileInformation
│       └── TrialInformation
│
├── Session1
│   │
│   ├── MicroPlot1
│   │       ├── Measurement1              ┐
│   │       │       ├── Sensor1           │  Data acquired at one particular time
│   │       │       │   └── Data          │  on the microplot.
│   │       │       └── SensorX           │
│   │       │           └── Data          ┘
│   │       └── MeasurementX
│   │
│   │       ├── Vector1                    ┐
│   │       │       ├── Head1              │  Invariant and defined once for the
│   │       │       │       ├── Sensor1    │  whole session. In a conventional
│   │       │       │       │   └── Calibration │ case of one HDF5 file per microplot,
│   │       │       │       └── SensorX    │  these data are duplicated in each
│   │       │       │           └── Calibration │ microplot file of the same session.
│   │       │       ├── StaticTransforms   │
│   │       │       ├── MeteorologicalSensorX │
│   │       │       ├── HeadX              │
│   │       │       ├── Scenario           │
│   │       │       └── Log                ┘
│   │       └── MicroPlotX
│   │
├── SessionX
        ├── MicroPlot1
        │   ...
        └── VectorX
```

6.1   Introduction to HDF5

The HDF5 format is essentially made up of groups, attributes and datasets.

The basic element is the attribute: individual or a set of metadata to be associated with the data to be stored.

These attributes can be of different types and are by definition limited in number (they accompany the dataset rather than replace it).

The dataset is the container for the data itself, which can be of any type.

This is defined when the dataset is created. It is possible to define as many datasets as there are different types of data to be stored.

In our application, each type of data will give rise to a specific dataset.

The group is the most important hierarchical element. It does not contain data directly but can contain other groups and datasets. It is also possible to associate attributes with them.

Each of these elements is uniquely named and self-documented (including data structure and size).

6.2 Data structure

This paragraph describes the organization of each type of data that may be found in the file, detailing the existing HDF5 Groups, Datasets and Attributes ("Nature" column), reproducing the hierarchical relationships between all these objects.

All dates and times below are in UTC.

The following two paragraphs (**"CommonSensorAttributes"** and **"GeometricSensorAttributes"**) describe the generic information and settings applicable to all sensor types.

"CommonSensorAttributes" attributes

These <u>mandatory</u> attributes must appear in all the sensor groups declared in "/Head{X}" group(s) (see §.6.2.4.1.a).

They do not appear in the sensor groups declared in "/MicroPlot{X}" group(s) containing only the acquired data datasets (see §.6.2.4.2).

Field	Nature	Type	Description
SensorId	Attribute	unsigned int	Unique ID of the sensor (of a same type)
SensorManufacturer	Attribute	string	Name of the sensor manufacturer
SensorModel	Attribute	string	Name of the sensor model declared by the manufacturer
SensorSerialNb	Attribute	string	Official sensor serial number or unique ID to link with additional information (for instance, for maintenance plan)
SensorURI	Attribute	string	URI of the sensor if involved
SensorFirmware	Attribute	string	Version of the sensor firmware if known
SensorDescription	Attribute	string	Explicit description of the sensor if needed (for instance, "nadir_camera")
DataFormatId	Attribute	unsigned int	ID of the data frame described in Part B of this document
HeadId	Attribute	unsigned int	ID of the measurement head in which the sensor is mounted

"GeometricSensorAttributes" attributes

These <u>optional</u> attributes may appear in sensor groups declared in "/Head{X}" group(s) (see §.6.2.4.1.a) if positioning information is needed and makes sense.

They do not appear in the sensor groups declared in "/MicroPlot{X}" group(s) containing only the acquired data datasets (see §.6.2.4.2).

Field	Nature	Type	Description
X	Attribute	double	Position of the sensor along X in the related geometric reference frame in meters
Y	Attribute	double	Position of the sensor along Y in the related geometric reference frame in meters
Z	Attribute	double	Position of the sensor along Z in the related geometric reference frame in meters
Roll	Attribute	double	Angle around the X-axis in degrees
Pitch	Attribute	double	Angle around the Y-axis in degrees
Yaw	Attribute	double	Angle around the Z-axis in degrees

6.2.1 "/MetaData" group

Field	Nature	Type	Description
/FileInformation	Group	-	Information related to the data container
/TrialInformation	Group	-	Information related to the experimental setup

6.2.2 "/FileInformation" group

Field	Nature	Type	Description
FormatName	Attribute	string	Name of the format described in the present specification : **PhenoHDF5**
VersionId	Attribute	string	Version of the present specification according to which the data were stored.

6.2.3   "/TrialInformation" group

Field	Nature	Type	Description
Campaign	Attribute	string	Year of harvest
Place	Attribute	string	Name of the locality
Field	Attribute	string	Name of the field or plot where the data were acquired
Experiment	Attribute	string	Name of the experimental setup
ExperimentId	Attribute	string	Coding of the experimental setup if needed
ExperimentURI	Attribute	string	URI of the experimental setup if needed
NationalInfrastructure	Attribute	string	Name of national infrastructure (i.e. "ARVALIS")
LocalInfrastructure	Attribute	string	Name of local infrastructure (i.e. "Phenofield")
Crop	Attribute	string	Name of the crop(s) concerned by the experiment

6.2.4   "/SessionX" group (X from 1 to N sessions)

A *Session* is defined as the amount of data acquired and associated metadata at a given date, with a given *Vector* in a given configuration (sensors, settings, geometry), for a given *Experiment* in a given *Campaign*.

Field	Nature	Type	Description
Date	Attribute	string	Date on which the session was launched in **YYYY-MM-DD_hh:mm:ss** format
SessionId	Attribute	unsigned int	ID of the session. In most cases, value is 1. May be useful for files containing several sessions.
Operator	Attribute	string	Name of the operator carrying out the measurements for this session.
Vector{X}	Group		Subgroup describing the vector used for the current session. See § 6.2.4.1 for details.
Microplot{X}	Group		Subgroup containing the data acquired on the microplot. See § 6.2.4.2 for details.

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6.2.4.1 "/VectorX" group (X from 1 to N vectors)

The aim of this group, as well as its subgroups, is to describe the measurement setup, such as the measurement head(s) and the sensor (number, type, geometry) that equip the head(s).

The group and subgroups do not contain measurement data but attributes (including **"CommonSensorAttributes"** and **"GeometricSensorAttributes"**) and possibly calibration data, useful for the global system description.

Field	Nature	Type	Description
EquipmentId	Attribute	string	Name of the acquisition device (such as Phenomobile, Literal, or UAV)
EquipmentSerialNb	Attribute	string	Serial number of the device
EquipmentURI	Attribute	string	URI of the device if needed
AcquisitionVersionId	Attribute	string	Version of the acquisition software installed on the device.
NumberOfHeads	Attribute	unsigned int	Number of measurement heads
/Head{X}	Group		Subgroup describing a measurement head embedded on the vector. See § a for details
StaticTransforms	Dataset		Array describing all the geometric frames used in the vector, as well as the parameters of the transformations to be applied to switch from one to another. See §.c for details
Mission	Dataset		Optional. Describes the mission information (settings and actions planned with sensors, path, etc.) See §. d for details
Log	Dataset		Optional. Logs of the acquisition system. See §. e for details

a. "/HeadX" group (X from 1 to N heads)

Field	Nature	Type	Description
ReferenceName	Attribute	string	Name of the geometric reference frame associated with the measurement head (to be declared in the "StaticTransforms" dataset. See § 6.2.4.1c for details)
HeadSerialNb	Attribute	string	Serial number of the measurement head

HeadURI	Attribute	string	URI of the measurement head if needed
/Positioning, /Camera{X}, /Lidar{X}, etc.	Group		Subgroups describing all the sensors embedded in the measurement head. See the following paragraphs for details.

a.1. "/PositioningX" group

Field	Nature	Type	Description
CommonSensorAttributes	Attribute	List of attributes	See description in the paragraph "CommonSensorAttributes" attributes
GeometricSensorAttributes	Attribute	List of attributes	See description in the paragraph "GeometricSensorAttributes" attributes.

a.2. "/CameraX" group (X from 1 to N cameras)

Field	Nature	Type	Description
CommonSensorAttributes	Attribute	List of attributes	See description in the paragraph "CommonSensorAttributes" attributes
GeometricSensorAttributes	Attribute	List of attributes	See description in the paragraph "GeometricSensorAttributes" attributes.
PixelFormat	Attribute	string	Description of the Bayer matrix layout according the GenICam standard: https://www.emva.org/wp-content/uploads/GenICamPixelFormatValues.pdf
PixelSize	Attribute	double	Pixel size in µm.
Width	Attribute	unsigned int	Width of the camera sensor in number of pixels.
Height	Attribute	unsigned int	Height of the camera sensor in number of pixels.
FocalLength	Attribute	double	Focal length of the lens in mm
Calibration	Dataset	Specific to the sensor	Optional. Calibration data if relevant, known and needed

a.3. "/TricamX" group (X from 1 to N tricams)

Field	Nature	Type	Description
CommonSensorAttributes	Attribute	List of attributes	See description in the paragraph "CommonSensorAttributes" attributes.
GeometricSensorAttributes	Attribute	List of attributes	See description in the paragraph "GeometricSensorAttributes" attributes.
Calibration	Dataset	Specific to the sensor	Calibration of each camera, and stereo calibration of RGB and RGB-NIR pairs
/CameraY (Y from 1 to 3)	Group		Subgroups describing the 3 cameras making up the Tricam sensor. See description above

a.4. "/LidarX" group (X from 1 to N lidars)

Field	Nature	Type	Description
CommonSensorAttributes	Attribute	List of attributes	See description in the paragraph "CommonSensorAttributes" attributes.
GeometricSensorAttributes	Attribute	List of attributes	See description in the paragraph "GeometricSensorAttributes" attributes.
Calibration	Dataset	Specific to the sensor	Optional. Calibration data if relevant, known and needed

a.5. "/Scanner3DX" group (X from 1 to N scanners)

Field	Nature	Type	Description
CommonSensorAttributes	Attribute	List of attributes	See description in the paragraph "CommonSensorAttributes" attributes.
GeometricSensorAttributes	Attribute	List of attributes	See description in the paragraph "GeometricSensorAttributes" attributes.
/SensorY	Group		Subgroups describing all the sensors making up the 3D scanner. See description below

a.6. "/SensorY" subgroup (Y from 1 to M sensors)

Field	Nature	Type	Description
GeometricSensorAttributes	Attribute	List of attributes	See description in the paragraph "CommonSensorAttributes" attributes.
SensorName	Attribute	String	Name of the sensor (for instance, Top-heading-east)
Calibration	Dataset	Specific to the sensor	Optional. Calibration data if known and needed

a.7. "/SpectrometerX" group (X from 1 to N spectrometers)

Field	Nature	Type	Description
CommonSensorAttributes	Attribute	List of attributes	See description in the paragraph "CommonSensorAttributes" attributes.
GeometricSensorAttributes	Attribute	List of attributes	See description in the paragraph "GeometricSensorAttributes" attributes.
AngularAperture	Attribute	double	Full aperture of the optic fiber in degrees.
Calibration	Dataset	Specific to the sensor	Optional. Calibration data if relevant, known and needed

a.8. "/SpectralSensorX" group (X from 1 to N spectral sensors)

Field	Nature	Type	Description
CommonSensorAttributes	Attribute	List of attributes	See description in the paragraph "CommonSensorAttributes" attributes.
GeometricSensorAttributes	Attribute	List of attributes	See description in the paragraph "GeometricSensorAttributes" attributes.
SensorType	Attribute	string	For instance, "NDVI" or "PRI."
/ChannelY	Group		Subgroups describing all the channels of the spectral sensor. See description below

a.9. "/ChannelY" subgroup (Y from 1 to M channels)

Field	Nature	Type	Description
Name	Attribute	string	Explicit name of the considered channel (for instance: zenith, upward, etc.)
ViewAngle	Attribute	double	View angle in the geometric reference frame in degrees
ScaleFactor	Attribute	double	Calibration scale factor. The final value is calculated as: $$value = voltage \times ScaleFactor + Offset$$
PreOffset	Attribute	double	Calibration offset. The final value is calculated as: $$value = (measure + PreOffset) \times ScaleFactor + PostOffset$$
PostOffset	Attribute	double	Calibration offset. The final value is calculated as:

			$value = (measure + PreOffset) \times ScaleFactor + PostOffset$
Wavelength	Attribute	double	Central wavelength of the considered channel in nm
Bandwidth	Attribute	double	Spectral bandwidth around the central wavelength of the channel in nm
Calibration	Dataset	Specific to the sensor	Optional. Calibration data if relevant, known and needed

a.10. "/MultispectralCameraX" group (X from 1 to N multispectral cameras)

Field	Nature	Type	Description
CommonSensorAttributes	Attribute	List of attributes	See description in the paragraph "CommonSensorAttributes" attributes.
GeometricSensorAttributes	Attribute	List of attributes	See description in the paragraph "GeometricSensorAttributes" attributes.
/BandY	Group		Subgroups describing all the bands of the multispectral camera. See description below

a.11. "/BandY" subgroup (Y from 1 to M bands)

Field	Nature	Type	Description
WaveLength	Attribute	double	Central wavelength of the considered band in nm
FocalLength	Attribute	Double	Focal length of the lens in mm
Calibration	Dataset	Specific to the sensor	Optional. Calibration data if relevant, known and needed

a.12. "/ThermalCameraX" group (X from 1 to N thermal cameras)

Field	Nature	Type	Description
CommonSensorAttributes	Attribute	List of attributes	See description in the paragraph "CommonSensorAttributes" attributes.
GeometricSensorAttributes	Attribute	List of attributes	See description in the paragraph "GeometricSensorAttributes" attributes.
PixelFormat	Attribute	string	Description of the pixel depth (Mono8, Mono1, etc.)
PixelSize	Attribute	double	Pixel size in µm.
Width	Attribute	unsigned int	Width of the camera sensor in number of pixels.
Height	Attribute	unsigned int	Height of the camera sensor in number of pixels.
FocalLength	Attribute	double	Focal length of the lens in mm

ScaleFactor	Attribute	double	Scale factor to be multiplied by the pixel raw value to obtain a temperature value in kelvin. Expressed in kelvin/count
B	Attribute	double	Calibration coefficient used to convert the sensor signal to temperature values in kelvin. Present if "ScaleFactor" is not set and if the camera raw data are kept rather than temperature values. The temperature T is obtained from the raw *value* as follows: $$T = \frac{B}{ln\left(\frac{R}{\frac{(value - J0)}{J1}} + F\right)}$$
R	Attribute	double	Calibration coefficient used to convert the sensor signal to temperature values in kelvin. Present if "ScaleFactor" is not set
F	Attribute	double	Calibration coefficient used to convert the sensor signal to temperature values in kelvin. Present if "ScaleFactor" is not set
J0	Attribute	double	Global offset. Present if "ScaleFactor" is not set
J1	Attribute	double	Global gain. Present if "ScaleFactor" is not set.
ShutterTemperatureDataFormatId	Attribute	unsigned int	ID of the shutter temperature data frame. See § 6.2.4.2a.12 and Part B § 8.2
Calibration	Dataset	Specific to the sensor	Optional. Other calibration data if relevant and needed. See Part B § 8.1

b. "/MeteorologicalSensorX" group (X from 1 to N meteorological sensors)

Field	Nature	Type	Description
CommonSensorAttributes	Attribute	List of attributes	See description in the paragraph "CommonSensorAttributes" attributes.
GeometricSensorAttributes	Attribute	List of attributes	See description in the paragraph "GeometricSensorAttributes" attributes.
SensorType	Attribute	string	May be "PAR", "ePAR", "MeteorologicalStation", "Anemometer", "BF5", …
/ChannelY	Group		Subgroup describing the channels of the meteorological sensor (optional, depending on the SensorType). See description at § a.9

c. "StaticTransforms" dataset

Where such information exists, it consists of matrices showing the passage from one point of reference to another on the vehicle in the form of rows with columns organized as follows:

Field	Nature	Type	Description
ReferenceName	Attribute	string	Name of the geometric frame in which the "ChildReferenceName" is referenced
ChildReferenceName	Attribute	string	Name of the geometric frame referenced in the "ReferenceName" geometric frame
X	Attribute	double	Position of the origin along X of the "ChildReferenceName" frame, in the "ReferenceName" frame, in meters
Y	Attribute	double	Position of the origin along Y of the "ChildReferenceName" frame, in the "ReferenceName" frame, in meters
Z	Attribute	double	Position of the origin along Y of the "ChildReferenceName" frame, in the "ReferenceName" frame, in meters
Roll	Attribute	double	Angle between the "ChildReferenceName" frame and the "ReferenceName" frame around the reference X-axis in degrees
Pitch	Attribute	double	Angle between the "ChildReferenceName" frame and the "ReferenceName" frame around the reference Y-axis in degrees

Yaw	Attribute	double	Angle between the "ChildReferenceName" frame and the "ReferenceName" frame around the reference Z-axis in degrees

d. "Mission" dataset

Optional. May contain the information related to the mission (settings of sensors, number frequency or places where acquisitions have to be made, path to follow in the field, etc.). Because this information is closely system-dependent, it may not be explained in the present document.

e. "Log" dataset

Optional. May contain the logs of the acquisition system. Should consist of ASCII content, but because this information is closely system-dependent, it may not be explained in the present document.

6.2.4.2 "/MicroPlotX" group (X from 1 to N microplots)

This group contains subgroups related to sensors that were actually acquired on the microplot. In this group, sensor subgroups have no attributes (attributes are declared in § 6.2.4.1) and contain only datasets.

Field	Nature	Type	Description
MicroPlotId	Attribute	string	Unique ID of the microplot.
MicroPlotURI	Attribute	string	URI of the microplot if needed.
Coordinates	Attribute	double[4][2]	Coordinates of the microplot. 2 possibilities: 1): decimal longitude and latitude of the 4 corners for a rectangular microplot in the WGS84 system. For instance, for the third point (= at index 2) *LonWGS84 = Coordinates[2][0]* *LatWGS84 = Coordinates[2][1]* 2): decimal longitude and latitude of the ellipse center in the WGS system, length of long axis and length of small axis in meters in case of an elliptical microplot. In this case, the unused coordinates are set to -1.
MicroPlotOrientation	Attribute	double	Orientation of the microplot relative to geographic north in degrees. See § 5.1.5
RowOrientation	Attribute	double	Orientation of seed rows relative to geographic north in degrees. See § 5.1.5

a. "/MeasurementX" group (X from 1 to N measurements)

This group distinguishes, for the same microplot in the same session, multiple acquisition passages (terrestrial systems, etc.) or multiple elevations (UAVs)

Field	Nature	Type	Description
Time	Attribute	string	Acquisition launch time in **YYYY-MM-DD_hh:mm:ss** format
HeadId	Attribute	unsigned int	ID of the measurement head used for the acquisition
/Positioning, /Camera{X}, /Lidar{X}, etc.	Group		Sensor subgroups containing the acquired data

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a.1.   "/Positioning" group

Field	Nature	Type	Description
Data	Dataset		Data package of one of the types described in Part B. See Part B § 1

a.2.   "/CameraX" group (X from 1 to N cameras)

For most systems:

Field	Nature	Type	Description
Data	Dataset		Data package of one of the types described in Part B. See Part B § 2

For UAVs:

Field	Nature	Type	Description
ExtractY	Group		Optional. See § 6.2.4.2a.14 for details

a.3.   "/TricamX" group (X from 1 to N tricams)

Field	Nature	Type	Description
/CameraY (Y from 1 to 3)	Attribute	List of attributes	See description in the paragraph "CommonSensorAttributes" attributes.
Data	Dataset		Data package of one of the types described in Part B. See Part B § 2

a.4.   "/LidarX" group (X from 1 to N lidars)

Field	Nature	Type	Description
Data	Dataset		Data package of one of the types described in Part B. See Part B § 3

a.5. "/Scanner3DX" group (X from 1 to N 3D scanners)

Field	Nature	Type	Description
/SensorY	Group		Subgroups describing all the sensors making up the 3D scanner. See description below

a.6. "/SensorY" subgroup (Y from 1 to M sensors)

Field	Nature	Type	Description
Data	Dataset		Data package of one of the types described in Part B. See Part B § 4

a.7. "/SpectrometerX" group (X from 1 to N)

Field	Nature	Type	Description
Data	Dataset		Data package of one of the types described in Part B. See Part B § 5

a.8. "/SpectralSensorX" group (X from 1 to N sensors)

Field	Nature	Type	Description
/ChannelY	Group		Subgroups describing all the channels of the spectral sensor. See description below
Data	Dataset		Data package containing the data processed from the different channel values, as described in Part B. See Part B § 6

a.9. "/ChannelY" subgroup (Y from 1 to M channels)

Field	Nature	Type	Description
Data	Dataset		Data package containing the raw data of the considered channel, as described in Part B. See Part B § 6

a.10. "/MultispectralCameraX" group (X from 1 to N)

For most systems:

Field	Nature	Type	Description
/BandY	Group		Subgroups describing all the bands of the multispectral camera. See description below

For UAVs:

Field	Nature	Type	Description
ExtractY	Group		Optional. See § 6.2.4.2a.14 for details

a.11. "/BandY" subgroup (Y from 1 to M bands)

Field	Nature	Type	Description
Data	Dataset		Data package of one of the types described in Part B. See Part B § 2

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a.12. "/ThermalCameraX" group (X from 1 to N)

For most systems:

Field	Nature	Type	Description
Data	Dataset		Data package of one of the types described in Part B. See Part B § 2
ShutterTemperature	Dataset		Data package described in Part B § 8.2

For UAVs:

Field	Nature	Type	Description
ExtractY	Group		Optional. See § 6.2.4.2a.14 for details

a.13. "/MeteorologicalSensorX" group (X from 1 to N sensors)

Field	Nature	Type	Description
Data	Dataset		Data package of one of the types described in Part B. See Part B § 7, except for DataFormatId=18.

Or, if DataFormatId=18 :

Field	Nature	Type	Description
/ChannelY	Group		Subgroups describing all the channels of the spectral sensor. See description below

a.14. "/ChannelY" subgroup (Y from 1 to M channels)

Field	Nature	Type	Description
Data	Dataset		Data package of one of the types described in Part B. See Part B § 7.1

a.15. "/ExtractX" group (X from 1 to N)

This group makes it possible to identify a trigger for a given imaging sensor and associate a number of metadata linked to the sensor's position at the measurement time with the area corresponding to the microplot in the original image and the reference of the original raw image from which this extract was taken.

This optional group pertains to devices, such as UAVs, acquiring raw data that cannot be directly assigned to a single microplot. In that special case, the data stored are typically data obtained after photogrammetry processing and cutting of original images around the microplots of the experimental setup.

An *Extract* is related to a trigger. There should be as many extracts as there are triggers associated with the microplot for a given sensor.

Field	Nature	Type	Description
/ExtractionDataX	Group		Subgroups describing all the extracts of the spectral sensor. See description below

a.16. "/ExtractionDataX" group (X from 1 to N)

Group containing the metadata and data associated with an extract for a given sensor.

An "ExtractionData" group is associated with a single data point. In the case of multi-band sensors producing one image per band, there are as many "ExtractionData" groups as there are bands.

Field	Nature	Type	Description
OriginalDataName	Attribute	string	Name or URL or URI of the original raw data
Longitude	Attribute	double	Recomputed longitude WGS84 of the sensor in degrees
Latitude	Attribute	double	Recomputed latitude WGS84 of the sensor in degrees
Altitude	Attribute	double	Recomputed altitude of the sensor in meters
Omega	Attribute	double	Angle between the camera viewing direction and the X-axis in degrees. The sign convention follows the right-hand rule.
Phi	Attribute	double	Angle between the camera viewing direction and the Y-axis in degrees. The sign convention follows the right-hand rule.
Kappa	Attribute	double	Angle between the camera viewing direction and the Z-axis in degrees. The sign convention follows the right-hand rule.
SensorAzimuthAngle	Attribute	double	Angle in the horizontal plane between the north and the vector defined by the position of the camera at the extract center. Positive towards the east, in degrees

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SensorZenitalAngle	Attribute	double	Angle in the vertical plane between the camera position projected on the ground and the vector defined by the position of the camera at the extract center. Always positive, in degrees
PixelDeviation	Attribute	double	Angle between the camera viewing direction and the vector defined from the optical center to the extract center projected on the ground, in degrees
PlotAreaCoveringRate	Attribute	unsigned int	Fraction of the microplot covered by the extract
GroundResolution	Attribute	unsigned int	Resolution of the pixel projected on the ground (cm/pixel)
BoundingBoxX	Attribute	Int	X-value of the top left corner of the bounding box of the extract in the original raw image in pixels
BoundingBoxY	Attribute	int	Y-value of the top left corner of the bounding box of the extract in the original raw image in pixels
BoundingBoxWidth	Attribute	unsigned int	Width of the bounding box of the extract in the original raw image in pixels
BoundingBoxHeight	Attribute	unsigned int	Height of the bounding box of the extract in the original raw image in pixels
NumberOfMaskPixels	Attribute	unsigned int	Number of pixels in the mask corresponding to the extract
ValidPixelsRate	Attribute	unsigned int	Rate of valid pixels in the mask corresponding to the extract
SaturatedPixelsRate	Attribute	unsigned int	Rate of saturated pixels in the mask corresponding to the extract
CalibrationQualityIndex	Attribute	int	Quality index of the applied calibration. -1 if unused.
BlurIndex	Attribute	int	Image blur index. -1 if unused.

a.17. "/Comments" group

This group is used to store comments entered by operators on the HMI of the acquisition system.

Field	Nature	Type	Description
Comments	Attribute	string	Comments and observations of operators.

a.18. "/GlobalCoverage" group

This group is used to store data relating to the experimental setup, such as orthoimages or point clouds from photogrammetry processing for instance.

Each of these types of data has an explicit subgroup and a dataset with data to be stored for each subgroup. To be expanded as required.

Field	Nature	Type	Description
/PointCloud	Group		Subgroup related to a point cloud
/Orthoimage	Group		Subgroup related to an orthoimage

a.19. "/PointCloud" subgroup

Field	Nature	Type	Description
Format	Attribute	int	ID of the data storage format (zip, las, laz, etc.). To be explained in Part B if needed.
Data	Dataset		Point cloud data

a.20. "/Orthoimage" subgroup

Field	Nature	Type	Description
Format	Attribute	int	ID of the data storage format (zip, jpg, tiff, etc.). To be explained in Part B if needed.
Data	Dataset		Orthoimage data

6.3   Writing a code for reading such a file

Writing a code for extracting this formatted data requires using a language for which HDF5 was implemented (C, C++, Python, Matlab, etc., see the [HDFGroup](#) site for details) and installing the appropriate HDF5 library.

When opening the file, you could write loops that browse all the objects contained in the file and write actions to be carried out for each group in § 6.2 that the file may contain and you are interested in.

In a first loop, you should first read the metadata (see § "/MetaData" group) and check the version of the current specification.

Then look at the "Session" group (§ 6.2.4) and start with the "Vector" group (§ 6.2.4.1). This step will make the acquisition system, the sensor composition and the settings known. If you have a whole session to process and have as many files as there are microplots in the experiment, this action only needs to be performed on the first file read.

In a separate loop for instance and once the context, experimental setup and acquisition system are known, you should open the Microplot "group" (§ 6.2.4.2), browse the data and run the process you want and need for it.

Part B: Description of the sensor raw data frames

- **Introduction**

The purpose of this document is to describe which kinds of data are available for each sensor embedded on the phenotyping data acquisition systems and how they are stored on the acquisition device.

The purpose of this part is to describe which kinds of data are ever available for each known sensor used for phenotyping measurements and how they are stored in data frames.

In this format, data are stored in binary format according to the little-endian layout without separators.

Unlike in CSV format, the first data point starts at the first byte of the file. With Python or C, for instance, opening a file for reading will require using the "rb" mode ('r' for reading and 'b' for binary).

Below are defined frames of known and supported data and sensor types.

In case of a missing definition or unsupported sensor, feel free to contact us at phenohdf5_contact@arvalis.fr so that we can improve this format for the community.

1 Positioning data

1.1 Geolocalized data

DataFormatId = 1

Data	Type of data	Comments
Acquisition date	64-bit integer	Date in the PC reference system in µs
Longitude	IEEE 754 double precision	WGS84 in decimal degrees
Latitude	IEEE 754 double precision	WGS84 in decimal degrees
Uncertainty on position	IEEE 754 double precision	Value in meters
Tray height	IEEE 754 double precision	Height of the measurement head above the ground in meters
Heading or Yaw	IEEE 754 double precision	Yaw angle (around Z-axis) in degrees
Course	IEEE 754 double precision	Value in degrees
Roll	IEEE 754 double precision	Roll angle (around X-axis) in degrees
Pitch	IEEE 754 double precision	Pitch angle (around Y-axis) in degrees
SOG (Speed over Ground)	IEEE 754 double precision	Speed in m/s

1.2 Geolocalized data with altitude

DataFormatId = 12

Data	Type of data	Comments
Acquisition date	64-bit integer	Date in the PC reference system in µs
Longitude	IEEE 754 double precision	WGS84 in decimal degrees
Latitude	IEEE 754 double precision	WGS84 in decimal degrees
Uncertainty on horizontal position	IEEE 754 double precision	Value in meters
Altitude	IEEE 754 double precision	Mean Sea Level (MSL) as in the GGA NMEA frame in meters

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Uncertainty on altitude	IEEE 754 double precision	Value in meters
Tray height	IEEE 754 double precision	Height of the measurement head above the ground in meters
Heading or Yaw	IEEE 754 double precision	Yaw angle (around Z-axis) in degrees
Course	IEEE 754 double precision	Value in degrees
Roll	IEEE 754 double precision	Roll angle (around X-axis) in degrees
Pitch	IEEE 754 double precision	Pitch angle (around Y-axis) in degrees
SOG (Speed over Ground)	IEEE 754 double precision	Speed in m/s

1.3   Linear data

DataFormatId = 8

Data	Type of data	Comments
Acquisition date	64-bits integer	Date in the PC reference system in µs
X position x	IEEE 754 double precision	Position along the X-axis in meters

1.4   Cartesian data

DataFormatId = 10

Data	Type of data	Comments
Acquisition date	64-bit integer	Date in the PC reference system in µs
X Position	IEEE 754 double precision	Position along the X-axis in meters
Y Position	IEEE 754 double precision	Position along the Y-axis in meters
Z Position	IEEE 754 double precision	Position along the Z-axis in meters
X Speed	IEEE 754 double precision	Speed along the X-axis in m/s
Y Speed	IEEE 754 double precision	Speed along the Y-axis in m/s
Z Speed	IEEE 754 double precision	Speed along the Z-axis in m/s

Apparent wind speed	IEEE 754 double precision	Value in m/s
Longitude	IEEE 754 double precision	WGS84 in decimal degrees
Latitude	IEEE 754 double precision	WGS84 in decimal degrees

1.5 Inertial Measurement Unit data

DataFormatId = 15

Data	Type of data	Comments
Acquisition date	64-bit integer	Date in the PC reference system in µs
Roll	IEEE 754 double precision	Roll angle (around X-axis) in degrees
Pitch	IEEE 754 double precision	Pitch angle (around Y-axis) in degrees
Yaw	IEEE 754 double precision	Yaw angle (around Z-axis) in degrees
Uncertainty on roll	IEEE 754 double precision	Roll standard deviation in degrees
Uncertainty on pitch	IEEE 754 double precision	Pitch standard deviation in degrees
Uncertainty on yaw	IEEE 754 double precision	Yaw standard deviation in degrees
Angular velocity X	IEEE 754 double precision	Angular speed around the X-axis in degrees/second
Angular velocity Y	IEEE 754 double precision	Angular speed around the Y-axis in degrees/second
Angular velocity Z	IEEE 754 double precision	Angular speed around the Z-axis in degrees/second
Linear acceleration X	IEEE 754 double precision	Linear acceleration along the X-axis in m/s²
Linear acceleration Y	IEEE 754 double precision	Linear acceleration along the Y-axis in m/s²
Linear acceleration Z	IEEE 754 double precision	Linear acceleration along the Z-axis in m/s²

1.6 Inclinometer data

DataFormatId = 7

Data	Type of data	Comments
Acquisition date	64-bit integer	Date in the PC reference system in µs
Angle	IEEE 754 double precision	Value in degrees

2 Camera data:

2.1 Raw frames

DataFormatId = 2

Data	Type of data	Comments
Acquisition date	64-bit integer	Date in the PC reference system in µs
Shutter time	32-bit integer	Shutter time in µs
Width	32-bit integer	Number of pixels per sensor line
Height	32-bit integer	Number of pixel lines
Nb of bytes per line	32-bit integer	Number of bytes per line
Pixel values	8-bit or 16-bit unsigned integers	Pixels of the image. (Height x Nb. of bytes per line) bytes to be read

2.2   Raw frames with gain

DataFormatId = 21

Data	Type of data	Comments
Acquisition date	64-bit integer	Date in the PC reference system in µs
Shutter time	32-bit integer	Shutter time in µs
Gain	IEEE 754 double precision	Gain applied in the camera
Gain unit	32-bit integer	0 : unitless (ISO value) 1 : dB 2 : unitless (linear gain)
Width	32-bit integer	Number of pixels per sensor line
Height	32-bit integer	Number of pixel lines
Nb of bytes per line	32-bit integer	Number of bytes per line
Pixel values	8-bit or 16-bit unsigned integers	Pixels of the image. (Height x Nb. of bytes per line) bytes to be read

2.3   JPG data

DataFormatId = 11

Data	Type of data	Comments
Acquisition date	64-bit integer	Date in the PC reference system in µs
File size	64-bit integer	JPG file size in number of bytes
Data (JPG format)	8-bit unsigned integers	Pixels and Exif

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2.4   TIFF data

DataFormatId = 9

Data	Type of data	Comments
Acquisition date	64-bit integer	Date in the PC reference system in µs
File size	64-bit integer	TIFF file size in number of bytes
Data (TIFF format)	8-bit unsigned integers	Pixels and Exif

3   LiDAR data

DataFormatId = 3

Data	Type of data	Comments
Acquisition date	64-bit integer	Date in the PC reference system in µs
Frequency	IEEE 754 float precision	Line frequency in hertz
Angle increment	IEEE 754 float precision	Angular resolution in degrees
Number of layers (N)	32-bit integer	Number of scan layers
Number of scans (M) in layer *N*	32-bit integer	Number of scans for the N layer
Angle	IEEE 754 float precision	Scan angle from horizontal axis in radians
Distance	IEEE 754 float precision	Distance from the optical center to the echo along scan angle in meters
Reflectivity	IEEE 754 float precision	Echo reflectivity, normalized between 0 and 1

N times (brace spanning from Number of scans row through Reflectivity row); M times (brace spanning from Angle through Reflectivity rows)

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4   3D scanner data

This sensor produces two PNG images corresponding to intensity and distance, as well as a point cloud in PLY format.

DataFormatId = 16

Data	Type of data	Comments
Acquisition date	64-bit integer	Date in the PC reference system in µs. Mean difference between the end and start of scan.
PNG g file size	64-bit integer	"g" PNG file size in bytes
PNG p file size	64-bit integer	"p" PNG file size in bytes
PLY file size	64-bit integer	PLY file size in bytes
PNG g data	8-bit unsigned integers	Content of PNG "g" file
PNG p data	8-bit unsigned integers	Content of PNG "p" file
PLY data	8-bit unsigned integers	Content of PLY file

5   Spectrometer data

DataFormatId = 4

Data	Type of data	Comments
Acquisition date	64-bit integer	Date in the PC reference system in µs
Integration time	IEEE 754 double precision	Integration time in ms
Cleaning sync mode	8-bit unsigned integer	Mode: 0 without cleaning, 1: with
Number of samples	32-bit integer	Number of samples in spectrum
Wavelength of sample N	IEEE 754 double precision	Wavelength of sample N in nm
Intensity of sample N	32-bit integer	Intensity of sample N, between 0 and 65535

N times (Wavelength of sample N, Intensity of sample N)

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6   Spectral indices data

DataFormatId = 17

Data	Type of data	Comments
Acquisition	64-bit integer	Date in the PC reference system in µs
Channel Y raw value (if linked to ChannelY subgroup)	IEEE 754 double precision	Raw signal for channel Y (for instance. 800 nm), in volts
Processed Spectral Index (if directly linked to SpectralIndice sensor)		NDVI or PRI computed from physical values (obtained from raw signal in volts and calibration data) according to the following formula: $$\frac{top_{ch2} - top_{ch1}}{top_{ch2} + top_{ch1}} - \frac{bottom_{ch2} - bottom_{ch1}}{bottom_{ch2} + bottom_{ch1}}$$

7   Meteorological sensors

7.1   *x*PAR data

DataFormatId = 18

Data	Type of data	Comments
Acquisition	64-bit integer	Date in the PC reference system in µs
Voltage	IEEE 754 double precision	Value in volts
*x*PAR	IEEE 754 double precision	Value (obtained from voltage and calibration data) in $\mu mol.m^{-2}.s^{-1}$

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7.2 Meteorological station data

DataFormatId = 19

Data	Type of data	Comments
Acquisition	64-bit integer	Date in the PC reference system in µs
Solar flux density	IEEE 754 double precision	Value in W/m²
Precipitation	IEEE 754 double precision	Value in mm
Number of thunderbolts	64-bit integer	Total number of thunderbolts since last acquisition
Distance of thunderbolts	IEEE 754 double precision	Distance of the closest thunderbolt in km
Wind speed	IEEE 754 double precision	Value in m/s
Wind direction	IEEE 754 double precision	Value in degrees
Max wind speed	IEEE 754 double precision	Maximum wind speed since last acquisition in m/s
Air temperature	IEEE 754 double precision	Value in Celsius
Vapor pressure	IEEE 754 double precision	Value in kPa
Absolute pressure	IEEE 754 double precision	Value in kPa
Relative humidity	IEEE 754 double precision	Value between 0 and 1
Humidity sensor temperature	IEEE 754 double precision	Value in Celsius
North/South angle of inclination	IEEE 754 double precision	Value in degrees
East/West angle of inclination	IEEE 754 double precision	Value in degrees

7.3 Anemometer data

DataFormatId = 5

Data	Type of data	Comments
Acquisition date	64-bit integer	Date in the PC reference system in µs

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Wind direction	IEEE 754 double precision	Value in degrees (0 -> 360 °)
Apparent instantaneous wind	IEEE 754 double precision	Value in m/s
Apparent average wind	IEEE 754 double precision	Value in m/s

7.4 Solar irradiation data

DataFormatId = 6

Data	Type of data	Comments
Acquisition date	64-bit integer	Date in the PC reference system in µs
Total	IEEE 754 double precision	Total solar radiation in W/m^2
Diffuse	IEEE 754 double precision	Diffuse solar radiation in W/m^2
Sunshine	Boolean	True: Sun up, False: Sun down

8 Thermal calibration data

8.1 Black body

DataFormatId = 13

Data	Type of data	Comments
Acquisition date	64-bit integer	Date in the PC reference system in µs
Temperature x Setpoint	IEEE 754 double precision	Value in degrees
Reference Temperature y	IEEE 754 double precision	Value in degrees
Ambient Temperature z	IEEE 754 double precision	Value in degrees
Relative Humidity x	IEEE 754 double precision	Value as percentage

8.2 Shutter temperature

DataFormatId = 20

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Data	Type of data	Comments
Acquisition date	64-bit integer	Date in the PC reference system in µs
Temperature	IEEE 754 double precision	Value in degrees

9   Micrometer data

DataFormatId = 14

Data	Type of data	Comments
Acquisition date	64-bit integer	Date in the PC reference system in µs
Number of measures	32-bit integer	Number N of measures
Diameter	IEEE 754 double precision	N values in meters