MISB Motion Imagery Standards Board	MISB RP 0801.4
RECOMMENDED PRACTICE	
Photogrammetry Metadata Set for Digital Motion Imagery	**24 October 2013**

1 Scope

This Recommended Practice presents the Key-Length-Value (KLV) metadata necessary for the dissemination of data required for the photogrammetric exploitation of motion imagery. The ability to geo-locate points on an image with known confidence is an important capability. The objective of this Recommended Practice is to support precise geopositioning.

Metadata in this Recommended Practice provides definitions and keys for individual elements. The intent is for other Standards to reference the metadata elements in this document and to include them in their respective data sets (e.g., truncation pack, floating length pack, local data set, etc.). This document concerns itself solely with the metadata specific to photogrammetry; metadata necessary for the primary exploitation of the motion imagery (including such elements as mission number, sensor type, platform type, etc.) and security metadata are not addressed in this Recommended Practice.

The metadata defined or called out herein is designed to be populated at the earliest possible point in the image chain for maximum fidelity. In most cases, this will be aboard the platform hosting the motion imagery sensor, although the improved point-positioning accuracy afforded by differential GPS techniques may dictate that some of these metadata be populated at the receipt station for the motion imagery essence.

2 References

2.1 Normative References

The following references and the references contained therein are normative.

[1] MISB ST 0807.12 MISB KLV Metadata Dictionary, Oct 2013
[2] SMPTE RP 210v13:2012 Metadata Element Dictionary
[3] MISB RP 1201 Floating Point To Integer Mapping, Feb 2012
[4] MISB ST 0107.1, Bit and Byte Order for Metadata in Motion Imagery Files and Streams, Jun 2011
[5] IEEE Standard for Floating-Point Arithmetic (IEEE 754)
[6] http://earth-info.nga.mil/GandG/geotrans/
[7] NIMA TR8350.2: Department of Defense World Geodetic System 1984, Its Definitions and Relationships with Local Geodetic Systems, 23 Jun 2004

[8] MISB RP 1202 Generalized Transformation Parameters, Oct 2013
[9] MISB RP 1010 Generalized Standard Deviation and Correlation Coefficient Metadata, Oct 2013

2.2 Informative References

[10] Fraser, C. S., M. R. and Ganci, G. *Multi-sensor system self-calibration.* Philadelphia, PA, 1995. SPIE Conference - Videometrics IV
[11] Hofmann-Wellenhof, B., H. Lichtenegger, and J. Collins. *GPS: Theory and Practice*. Vienna: Springer-Verlag, 1997
[12] Mikhail, Edward M., James S. Bethel, and J. Chris McGlone. *Introduction to Modern Photogrammetry*. New York: John Wiley & Sons, Inc., 2001

3 Revision History

Revision	Date	Summary of Changes
0801.4	09/30/2013	Major revision of RG 0801, the majority of document restructured • Pixel Size Y key corrected • Removed Truncation Packs • Removed all variance and covariance keys • Removed GPS DOP and platform related keys • Deprecated first form of the old Image Size TP • Removed independent keys. They are no longer required. • Added: measured Line/Sample/LRF Divergence keys • Upgraded to Recommended Practice

4 Abbreviations and Acronyms

CSM Community Sensor Model
ECEF Earth-Centered, Earth Fixed
GPS Global Positioning System
IMU Inertial Measurement Unit
KLV Key-Length-Value
LRF Laser Range Finder
NED North-East-Down
SI International System of Units
WGS-84 World Geodetic System of 1984

5 Introduction

This Recommended Practice provides definitions and keys for individual elements for the transmission of photogrammetric metadata values within motion imagery streams from the sensor to the end client for frame-accurate exploitation of the photogrammetric motion imagery.

6 Photogrammetry Metadata Sets

This document organizes photogrammetric metadata into three photogrammetric metadata groups: External Parameters, Internal Parameters and Miscellaneous Parameters as listed below:

1) Photogrammetry External Parameters (Section 6.3)
    a. Sensor Position
    b. Sensor Velocity
    c. Sensor Absolute Orientation
    d. Sensor Absolute Orientation Rate
2) Photogrammetry Internal Parameters (Section 6.4)
    a. Boresight
    b. Image Size
    c. Focal Plane
    d. Radial Distortion
    e. Tangential-Decentering
    f. Affine Correction
3) Miscellaneous Parameters (Section 6.5)
    a. Slant Range

6.1 Organization of the Photogrammetry Metadata

The metadata tables describe in detail the parameters of Photogrammetry Metadata for Digital Motion Imagery.

Each table of metadata elements has the following columns:

- Name – A descriptive name for the metadata item.
- Symbol – The symbol name for the metadata element as it appears in STD 0807[1] or SMPTE RP 210[2].
- Key – The full 16-byte key value as defined in STD 0807[1] or SMPTE RP 210[2].
- Units – Units of measure in SI units, if appropriate.
- Format – Value encoding method, which can be one of the following:
    - UINT(<length>): an Unsigned integer of <length> bytes.
        - Example: UINT(8) is an unsigned integer of 8 bytes.
    - IMAPB(<min float>, <max float>, <length>): MISB RP 1201[3] notation for mapping (“packing”) a floating point value into an integer value.
        - Example: IMAPB(-1234,+1234,3) indicates that a floating point value within the range from -1234.0 to +1234.0 is to be mapped into 3 bytes.
    - FLOAT(<length>): a floating point value of <length> bytes.
        - Example: FLOAT(4) is a 32-bit IEEE floating point number.

6.2 Conventions

Requirement	
RP 0801.4-01	All KLV-encoded metadata shall be expressed in accordance with MISB ST 0107[4].
RP 0801.4-02	Floating point values shall comply with IEEE 754[5].
RP 0801.4-03	Measurements shall be expressed using the International System of Units (SI).

To promote bit efficiency, floating point values may be "packed" as integers, in accordance with MISB RP 1201[3].

All angle measurements are in half circles. To obtain the value of an angle in radians, multiply the number of half circles in the measurement by pi (π). Angle measurements are packed as integer representations of rational numbers.

pi (π) is defined as: $\pi = 3.1415926535\ 8979324$

This is the value of pi used in the coordinate conversion software developed and controlled by NGA; specifically, MSP GEOTRANS 3.0 (Geographic Translator) [6].

Requirement	
RP 0801.4-04	When converting values between radians and half circles, the value of pi (π) shall be 3.1415926535 8979324.

6.3 Photogrammetry External Parameters

The External Parameters relate the sensor to the "real world", using the World Geodetic System-1984 (WGS-84) coordinate frame. All of the position coordinates and velocity elements are given with respect to this coordinate reference.

In this Recommended Practice, WGS-84 coordinates are specified using a Cartesian, Earth-Centered, Earth-Fixed (ECEF) coordinate system, with the x-axis pointing towards the equator along the Greenwich meridian, the z-axis pointing towards the North Pole (true North), and the y-axis completing the right-handed coordinate system[7]. The point (0, 0, 0) is defined as the center of mass of the Earth. Measurements are expressed using the International System of Units (SI).

Requirement	
RP 0801.4-05	Sensor position and velocity shall be expressed using the WGS-84 Earth-Centered, Earth-Fixed (ECEF) coordinate frame.

This coordinate system is consistent with the native coordinate format of the Global Positioning System (GPS). If it is necessary to later transform these coordinates into another systems (e.g., Latitude, Longitude, and Height-Above-Ellipsoid), care must be taken to avoid introducing errors through such a coordinate transformation.

The orientation of the sensor is expressed relative to a "local" coordinate frame, using a North-East-Down (NED) system at the location of the sensor. Figure 1 depicts the orientation of the

local coordinate system relative to the ECEF coordinate system. Section 7 gives a description, with corresponding figures, of the rotation angles relative to the local coordinate system, where they are applied sequentially as heading-pitch-roll.

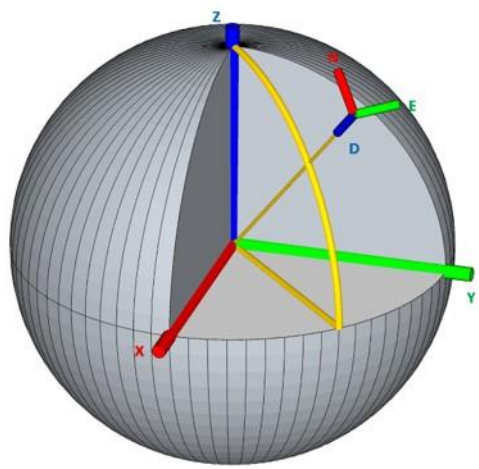

Figure 1: The Local coordinate system relative to the ECEF coordinate system

Requirement	
RP 0801.4-06	Sensor orientation shall be expressed using a North-East-Down (NED) coordinate frame located at the Earth-Centered, Earth-Fixed (ECEF) position of the sensor.

6.3.1 Sensor Position Metadata

The sensor position metadata set is used to describe a reference point within a sensor. An example of this reference point is the center of rotation of the sensor (i.e., the point about which a two- or three-axis gimbal rotates). The center of rotation is a point of convenience, because its location does not change depending on the sensor orientation relative to the platform's reference frame. This metadata set includes elements for the ECEF position coordinates of the sensor. The intended use of this metadata set is to perform photogrammetric computations, which are based on the sensor perspective center. (The sensor perspective center is analogous to the pinhole of a pinhole camera.) This metadata set alone does not describe the sensor perspective center, but when used with the Boresight metadata set, described in Section 6.4.2, it gives the exact location needed in the photogrammetric computations. The sensor position metadata is listed in Table 1.

Table 1: Sensor Position Metadata

Name	Symbol	Key	Units	Format
Sensor ECEF Position Component X	[sensor_ecef_x]	06.0E.2B.34.01.01.01.01.0E.01.02.01.25.00.00.00 (CRC 25208)	meters	IMAPB(-1e9, 1e9, 5)
Sensor ECEF Position Component Y	[sensor_ecef_y]	06.0E.2B.34.01.01.01.01.0E.01.02.01.26.00.00.00 (CRC 63908)	meters	IMAPB(-1e9, 1e9, 5)

Sensor ECEF Position Component Z	[sensor_ecef_z]	06.0E.2B.34.01.01.01.01.0E.01.02.01.27.00.00.00 (CRC 36624)	meters	IMAPB(-1e9, 1e9, 5)

6.3.2 Sensor Velocity Metadata

The sensor velocity metadata set includes the ECEF velocity components of the sensor. The sensor velocity metadata is listed in Table 2.

Table 2: Sensor Velocity Metadata

Name	Symbol	Key	Units	Format
Sensor ECEF Velocity Component X	[sensor_ecef_xdot]	06.0E.2B.34.01.01.01.01.0E.01.02.01.2E.00.00.00 (CRC 31847)	m/s	IMAPB(-25e3, 25e3, 3)
Sensor ECEF Velocity Component Y	[sensor_ecef_ydot]	06.0E.2B.34.01.01.01.01.0E.01.02.01.2F.00.00.00 (CRC 2771)	m/s	IMAPB(-25e3, 25e3, 3)
Sensor ECEF Velocity Component Z	[sensor_ecef_zdot]	06.0E.2B.34.01.01.01.01.0E.01.02.01.30.00.00.00 (CRC 50586)	m/s	IMAPB(-25e3, 25e3, 3)

6.3.3 Sensor Absolute Orientation Metadata

The Sensor Absolute Orientation Parameters are sensor Heading, Pitch, and Roll angles. (Heading may also be referred to as “azimuth”.) These parameters specify sensor orientation with respect to a North-East-Down frame of reference located at the sensor perspective center. These parameters describe the direction in which the sensor “Reference Axis” is pointing. The combination of the sensor Reference Axis and the Boresight metadata set described in Section 6.4.2 defines the sensor Principal Axis. This Principal Axis is also known as the sensor line-of-sight axis, or boresight. A detailed explanation appears in Section 7.

The Heading of a sensor is the angle from True North to the boresight vector projected onto the local horizontal plane. Range of values is 0 to (almost) 2 half-circles; North is 0, East is 0.5 half-circles; South is 1 half-circle, and West is 1.5 half-circles.

The Pitch of a sensor describes the angle its boresight vector makes with the horizontal, where the vertical is perpendicular to the ellipsoid; positive (negative) angles describe a nose up (down) orientation. Range of values is -1.0 half-circles to +1.0 half-circles.

The Roll of a sensor is the angle, defined as positive clockwise, that rotates the image about the boresight vector to complete the sensor orientation. This value is given in half-circles from -1.0 to +1.0.

The heading-pitch-roll transformation is customarily described using a rotation matrix, described in Section 7.

The azimuth-pitch-roll formulation of the rotation matrix has a known singularity point where the pitch angle is equal to +90 degrees or -90 degrees. During calculation, caution must be used

to avoid errors as the sensor passes through these discontinuity points. This topic is discussed at the end of Section 7.

Note that heading, pitch, and roll must be applied in a strict sequence, as described in Figure 5, Figure 6, and Figure 7 of Section 7.

Requirement	
RP 0801.4-07	During coordinate system transformation calculations, sensor rotation angles shall be applied in the sequence (1) heading, (2) pitch, and (3) roll.

The sensor absolute orientation metadata is listed in Table 3.

Table 3: Sensor Absolute Orientation Metadata

Name	Symbol	Key	Units	Format
Sensor Absolute Heading	[sensor_absolute_heading]	06.0E.2B.34.01.01.01.01. 0E.01.02.01.37.00.00.00 (CRC 38071)	half circles	IMAPB(0, 2,4)
Sensor Absolute Pitch	[sensor_absolute_pitch]	06.0E.2B.34.01.01.01.01. 0E.01.02.01.38.00.00.00 (CRC 16473)	half circles	IMAPB(-1, 1, 4)
Sensor Absolute Roll	[sensor_absolute_roll]	06.0E.2B.34.01.01.01.01. 0E.01.02.01.39.00.00.00 (CRC 14061)	half circles	IMAPB(-1, 1, 4)

6.3.4 Sensor Absolute Orientation Rate Metadata

The definitions and sign conventions for the Sensor Absolute Orientation Rates (time rate of change) are the same as those given in Section 6.3.3.

The sensor absolute orientation rate metadata set includes the Sensor Absolute Orientation Rate components (in half-circles per second) of the sensor. The sensor absolute orientation rate metadata is listed in Table 4.

Table 4: Sensor Absolute Orientation Rate Metadata

Name	Symbol	Key	Units	Format
Sensor Absolute Heading Rate	[sensor_heading_rate]	06.0E.2B.34.01.01.01.01. 0E.01.02.01.40.00.00.00 (CRC 34799)	half circles /sec	IMAPB(-1, 1, 2)
Sensor Absolute Pitch Rate	[sensor_pitch_rate]	06.0E.2B.34.01.01.01.01. 0E.01.02.01.41.00.00.00 (CRC 61787)	half circles /sec	IMAPB(-1, 1, 2)
Sensor Absolute Roll Rate	[sensor_roll_rate]	06.0E.2B.34.01.01.01.01. 0E.01.02.01.42.00.00.00 (CRC 27271)	half circles /sec	IMAPB(-1, 1, 2)

6.4 Photogrammetry Internal Parameters

Within photogrammetry, data values representing the configuration and orientation of optical sensor/detector systems behind a lens or aperture are commonly referred to as the internal parameters. These parameters represent a full and complete description of the internal sensor geometry.

In photogrammetry applications for digital motion imagery, these internal parameters enable transformation calculations between pixel coordinate systems and image space coordinate systems. The metadata definitions for the internal parameters described here provide representation of known systematic errors in the imaging system.

The transformation between pixel and image space coordinate systems must use coordinates referenced to the full image resolution.

Requirement	
RP 0801.4-08	Transformation between pixel and image space coordinate systems shall use image coordinates at full image resolution.

6.4.1 Pixel Coordinate Transformation

To align with photogrammetry community conventions, this document uses the Community Sensor Model (CSM) definitions of three commonly used pixel coordinate systems for physical focal plane arrays and digital images: row and column; line and sample; and (x, y). The first two use units of pixels (as shown in Figure 2 and Figure 3), and the third uses physical measures, such as, millimeters (shown in Figure 4).

The objective is to map pixel coordinates to an x-y coordinate system with its origin coincident with the Principal Axis. This coordinate transformation forms the basis of the Interior Orientation parameters described in this document, and is considered to be the default coordinate system for representing internal camera parameters as metadata.

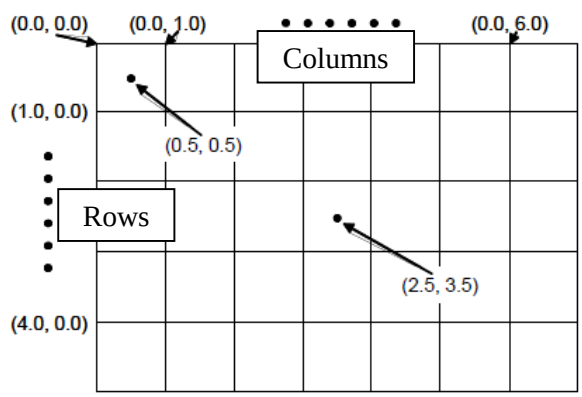

Figure 2: Row and Column Coordinates

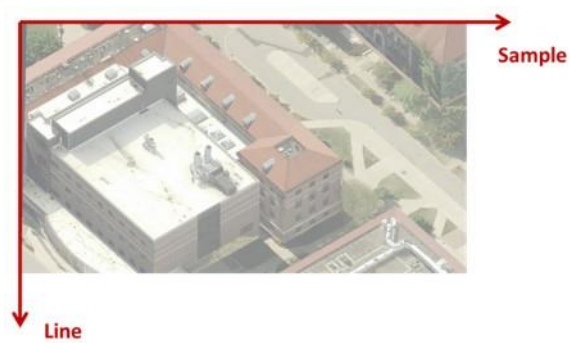

Figure 3: Line and Sample Coordinates

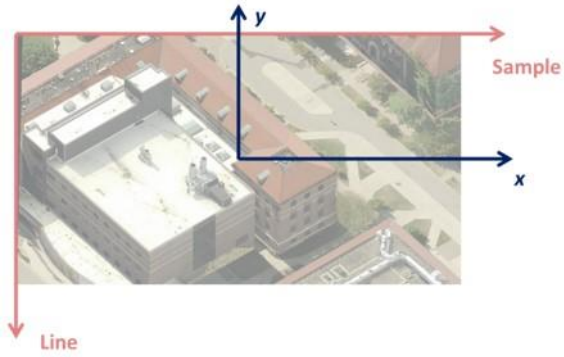

Figure 4: Line and Sample Coordinates and Measured Coordinates

Additional forms of pixel to image mappings for chips, digitally zoomed images, or other types of general transformations are defined in MISB RP 1202[8].

6.4.2 Boresight Metadata

The Boresight Offset Delta X, Delta Y, and Delta Z parameters represent the mathematical translation from the origin of the sensor coordinate frame to the origin of the sensor perspective center. The rotational offsets Delta Angle 1, Delta Angle 2, and Delta Angle 3 are angular rotations applied to the sensor Reference Axis to align with the sensor Principal Axis. Delta Angle 1 represents the rotation about the twice-rotated x-axis of the sensor reference frame. Delta Angle 2 represents the rotation about the once-rotated y-axis of the sensor reference frame. Delta Angle 3 represents the rotation about the z-axis of the sensor reference frame.

The rotations are applied in the following order: (1) apply the Delta Angle 3 rotation about the z-axis of the sensor reference frame; (2) next apply the Delta Angle 2 rotation about the once-rotated y-axis of the sensor reference frame; and (3) finally apply the Delta Angle 1 rotation about the twice-rotated x-axis of the sensor reference frame. These sequential rotations will rotate the measured sensor reference frame to the sensor optical line of sight reference frame. If the sensor reference frame is aligned to the sensor optical axis, the three boresighting angles will be equal to zero.

See Section 7 for figures describing the rotations and for further information on the application of the boresight offsets. The boresight metadata is listed in Table 5.

Table 5: Boresight Metadata

Name	Symbol	Key	Units	Format
Boresight Offset Delta X	[boresight_offset_delta_x]	06.0E.2B.34.01.01.01.01. 0E.01.02.02.18.00.00.00 (CRC 39365)	m	IMAPB(-300, 300, 2)
Boresight Offset Delta Y	[boresight_offset_delta_y]	06.0E.2B.34.01.01.01.01. 0E.01.02.02.19.00.00.00 (CRC 61297)	m	IMAPB(-300, 300, 2)

Boresight Offset Delta Z	[boresight_offset_delta_z]	06.0E.2B.34.01.01.01.01. 0E.01.02.02.1A.00.00.00 (CRC 29869)	m	IMAPB(-300, 300, 2)
Boresight Delta Angle 1	[boresight_delta_angle_1]	06.0E.2B.34.01.01.01.01. 0E.01.02.02.1B.00.00.00 (CRC 00537)	half circles	IMAPB(-0.25, 0.25, 4)
Boresight Delta Angle 2	[boresight_delta_angle_2]	06.0E.2B.34.01.01.01.01. 0E.01.02.02.1C.00.00.00 (CRC 21300)	half circles	IMAPB(-0.25, 0.25, 4)
Boresight Delta Angle 3	[boresight_delta_angle_3]	06.0E.2B.34.01.01.01.01. 0E.01.02.02.1D.00.00.00 (CRC 09600)	half circles	IMAPB(-0.25, 0.25, 4)

6.4.3 Image Size Metadata

The image size metadata set provides the number of image rows (i.e. the image height), the number of image columns (i.e. the image width), the size of the pixels in the x-direction, and the size of the pixels in the y-direction. The transformation from pixel coordinates to image-space coordinates is given by in MISB RP 1202[8]. The image size metadata is listed in Table 6.

Table 6: Image Size Metadata

Name	Symbol	Key	Units	Format
Image Rows	[image_rows]	06.0E.2B.34.01.01.01.01. 0E.01.02.02.06.00.00.00 (CRC 08248)	pixels	UINT(2)
Image Columns	[image_columns]	06.0E.2B.34.01.01.01.01. 0E.01.02.02.07.00.00.00 (CRC 22156)	pixels	UINT(2)
Pixel Size X	[pixel_size_x]	06.0E.2B.34.01.01.01.01. 0E.01.02.02.82.00.00.00 (CRC 14321)	mm	IMAPB(1e-4, 0.1, 2)
Pixel Size Y	[pixel_size_y]	06.0E.2B.34.01.01.01.01. 0E.01.02.02.82.01.00.00 (CRC 00193)	mm	IMAPB(1e-4, 0.1, 2)

Requirement	
RP 0801.4-09	When the pixel size in the y direction is unspecified, it shall be assumed equal to the pixel size in the x direction indicating square pixels.

6.4.4 Focal Plane Metadata

The focal plane metadata set provides information about the sensor focal plane and imaging geometry. It contains the Principal Point offset and the effective focal length of the sensor. The focal plane metadata is listed in Table 7.

Table 7: Focal Plane Metadata

Name	Symbol	Key	Units	Format
Focal Plane Line Principal Point Offset	[focal_plane_principal_point_offset]	06.0E.2B.34.01.01.01.01.0E.01.02.02.03.00.00.00 (CRC 40061)	mm	IMAPB(-25, 25, 2)
Focal Plane Sample Principal Point Offset	[focal_plane_sample_point_offset]	06.0E.2B.34.01.01.01.01.0E.01.02.02.04.00.00.00 (CRC 52560)	mm	IMAPB(-25, 25, 2)
Sensor Calibrated / Effective Focal Length	[sensor_cal_eff_focal_length]	06.0E.2B.34.01.01.01.01.0E.01.02.02.05.00.00.00 (CRC 48100)	mm	IMAPB(0, 10000, 4)

6.4.5 Radial Distortion Metadata

The radial distortion metadata set provides parameters needed to correct for barrel or pincushion distortions in the sensor optics. Radial lens distortion d_r for image coordinates *x* and *y* is modeled as a polynomial function of the radial distance *r* from the Principal Point. The radial distortion parameters are the k_0, k_1, k_2, and k_3 parameters of Equation 1.

$$d_r = k_0 r + k_1 r^3 + k_2 r^5 + k_3 r^7 \qquad \textbf{Equation 1}$$

where $\bar{x} = x - x_0 \qquad \bar{y} = y - y_0 \qquad r = \sqrt{\bar{x}^2 + \bar{y}^2}$

and x_0 and y_0 are the coordinates of the Principal Point.

This model of radial distortion has a limited range for which the residuals of the fit are considered acceptable. This "valid range" is a distance in image space (mm) radially from the principal point. The radial distortion rate metadata is listed in Table 8.

Table 8: Radial Distortion Metadata

Name	Symbol	Key	Units	Format
Valid Range of Radial Distortion	[Valid_range_radial_distortion]	06.0E.2B.34.01.01.01.01.0E.01.02.02.69.00.00.00 (CRC 44292)	mm	FLOAT(4)
Radial Distortion Constant Parameter	[radial_distortion_constant_parameter]	06.0E.2B.34.01.01.01.01.0E.01.02.02.6A.00.00.00 (CRC 14040)	mm/(mm)	FLOAT(4)
First Radial Distortion Parameter	[first_radial_distortion_parameter]	06.0E.2B.34.01.01.01.01.0E.01.02.02.0A.00.00.00 (CRC 28426)	mm/(mm)^3	FLOAT(4)
Second Radial Distortion Parameter	[second_radial_distortion_parameter]	06.0E.2B.34.01.01.01.01.0E.01.02.02.0B.00.00.00 (CRC 06590)	mm/(mm)^5	FLOAT(4)

Third Radial Distortion Parameter	[third_radial_distortion_parameter]	06.0E.2B.34.01.01.01.01.0E.01.02.02.0C.00.00.00 (CRC 18579)	mm/(mm)^7	FLOAT(4)

6.4.6 Tangential-Decentering Metadata

The tangential-decentering metadata set provides tangential decentering parameters P_1, P_2, and P_3 to correct image coordinates x and y for these distortions using Equation 2.

$$\Delta x_{decen} = (1 + P_3 r^2)[P_1(r^2 + 2\bar{x}^2) + 2P_2\bar{x} \times \bar{y}]$$
$$\Delta y_{decen} = (1 + P_3 r^2)[2P_1\bar{x} \times \bar{y} + P_2(r^2 + 2\bar{y}^2)]$$

Equation 2

where Δx_{decen} and Δy_{decen} are the x and y components of the decentering effect.

$$\bar{x} = x - x_0 \qquad \bar{y} = y - y_0 \qquad r = \sqrt{\bar{x}^2 + \bar{y}^2}$$

where x_0 and y_0 are the coordinates of the Principal Point.

The tangential-decentering metadata is listed in Table 9.

Table 9: Tangential-Decentering Metadata

Name	Symbol	Key	Units	Format
First Tangential / Decentering Parameter	[first_tan_decenter_parameter]	06.0E.2B.34.01.01.01.01.0E.01.02.02.0D.00.00.00 (CRC 15911)	mm/(mm)^2	FLOAT(4)
Second Tangential / Decentering Parameter	[second_tan_decenter_parameter]	06.0E.2B.34.01.01.01.01.0E.01.02.02.0E.00.00.00 (CRC 42491)	mm/(mm)^2	FLOAT(4)
Third Tangential / Decentering Parameter	[third_tan_decenter_parameter]	06.0E.2B.34.01.01.01.01.0E.01.02.02.83.00.00.00 (CRC 16709)	1/(mm)^2	FLOAT(4)

6.4.7 Affine Correction Metadata

The affine correction metadata set provides affine correction parameters. Parameter b_1 is a differential scale correction parameter, and parameter b_2 is a skew correction.

$$\Delta x_{skew-scale} = b_1\bar{x} + b_2\bar{y}$$
$$where$$
$$\bar{x} = x - x_0$$
$$\bar{y} = y - y_0$$

Equation 3

Where x_0 and y_0 are the principal point offsets in the x and y directions, respectively; and x and y are the image coordinates in the frame coordinate system. The affine correction metadata is listed in Table 10.

Table 10: Affine Correction Metadata

Name	Symbol	Key	Units	Format
Differential Scale Affine Parameter	[differential_scale_affine_parameter]	06.0E.2B.34.01.01.01.01.0E.01.02.02.0F.00.00.00 (CRC 54095)	mm/mm	FLOAT(4)
Skewness Affine Parameter	[skew_affine_parameter]	06.0E.2B.34.01.01.01.01.0E.01.02.02.10.00.00.00 (CRC 07174)	mm/mm	FLOAT(4)

Requirement	
RP 0801.4-10	If pixels are not square, the differential scale correction parameter b_1 shall be exactly zero.

6.5 Photogrammetry Miscellaneous Parameters

The following subsection describes parameters that are neither interior nor exterior orientation parameters; however, they are useful when describing the data collected from a motion imagery sensor.

6.5.1 Slant Range Metadata

Slant Range is defined in SMPTE RP 210[2].

Requirement	
RP 0801.4-11	The definition of slant range shall be as defined in SMPTE RP 210[2].

Slant Range is the distance from the sensor to a point on the ground contained in the framed subject (image) depicted in the captured essence. When used in this metadata set, the position of the sensor is defined to be the position of its perspective center.

A pedigree component exists to describe the derivation of the slant range value. Three options are defined: (0) Other, indicated by a value of zero; (1) Measured, indicated by a value of 1; and (2) Computed, indicated by a value of 2.

Typically, a measured range value might be obtained using a laser range finder.

Requirement	
RP 0801.4-12	When the slant range pedigree value is absent from the metadata set, but a slant range value is specified, the pedigree value shall be assumed to be 1 (a measured range).

A line and sample coordinate for the slant range is included in this metadata set to indicate the coordinate within the scene for which the value applies. Typically, this will be at the center of the image.

For measurements obtained using a laser range finder, the metadata set includes a laser range finder (LRF) divergence value to quantify the divergence of the laser range finder. The slant range metadata is listed in Table 11.

Table 11: Slant Range Metadata

Name	Symbol	Key	Units	Format
Slant Range	Key defined in SMPTE RP210[2]	06.0E.2B.34.01.01.01.01.07.01.08.01.01.00.00.00 (CRC 16588)	meters	FLOAT(4)
Slant Range Pedigree	[slant_range_pedigree]	06.0E.2B.34.01.01.01.01.0E.01.02.02.87.00.00.00 (CRC 35764)		UINT(1)
Measured Line Coordinate for Range	[range_measured_line_coordinate]	06.0E.2B.34.01.01.01.01.0E.01.02.05.07.00.00.00 (CRC 12632)	pixels	FLOAT(4)
Measured Sample Coordinate for Range	[range_measured_sample_coordinate]	06.0E.2B.34.01.01.01.01.0E.01.02.05.08.00.00.00 (CRC 58806)	pixels	FLOAT(4)
LRF Divergence	[lrf divergence]	06.0E.2B.34.01.01.01.01.0E.01.02.05.09.00.00.00 (CRC 37634)	radians	FLOAT(4)

6.6 Error Propagation

This document provides a "library" of metadata elements that may be incorporated into aggregate KLV data structures (e.g., local sets) of other specifications (Standards, Recommended Practices, and Engineering Guidelines). To comply with the objective that these metadata elements support precise geolocation, any containing specification must also include appropriate uncertainty information.

Requirement	
RP 0801.4-13	Specifications that include any of the photogrammetry parameters defined in this specification shall include related variance-covariance uncertainty information.
RP 0801.4-14	Uncertainty information regarding photogrammetry parameters defined in this specification shall be encoded in accordance with MISB RP 1010[9].

7 Appendix – Rotation Angle Definitions

This appendix provides additional information for applying the information contained in this Recommended Practice.

Establishing a convention for rotating a coordinate system to be parallel to another coordinate system requires choosing from a variety of methods that yield the same result. This RP uses the azimuth-pitch-roll sequence (termed "heading-pitch-roll" in the body of this document) for the

rotations. To avoid errors in interpretation, the azimuth, pitch, and roll angles must be defined unambiguously with respect to the starting and ending coordinate systems.

This section of the appendix will describe the starting coordinate system, the ending coordinate system, and the prescription of the angles used to align the two systems.

The initial coordinate system in which the angles are referenced is a North-East-Down (NED) system, centered at the sensor perspective center. The NED reference frame is a right-handed coordinate system with North being analogous to the x-axis, East being analogous to the y-axis, and Down being analogous to the z-axis. The destination coordinate system is the principal coordinate system, which is a right-handed system with its origin at the perspective center. The line-of-sight axes will be aligned where the x-axis is pointing along the sensor line-of-sight vector, the y-axis is parallel to the rows in the image, and the z-axis is parallel to the columns in the image.

The first angle of rotation aligns the x-axis (North) with the projection of the sensor boresight vector into a horizontal plane by rotating about the NED z-axis (Down). This is illustrated below in Figure 5, where the x-axis is colored red, the y-axis is colored green, and the z-axis is colored blue. The magnitude of this angle is equal to the azimuth, where a positive angle is in the clock-wise direction when looking in the "down" direction; in other words, positive moves the red-axis (x-axis) to the green-axis (y-axis). The angle labeled in the figure, A3, is equivalent to the azimuth.

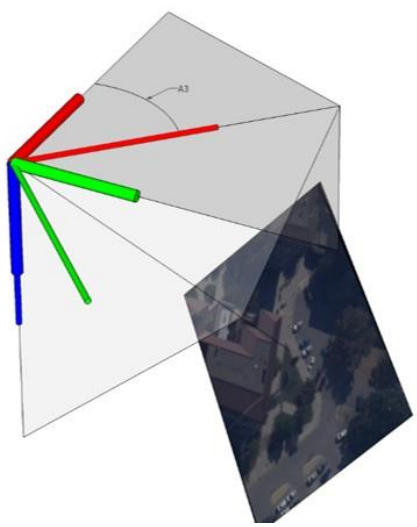

Figure 5: Description of the azimuth rotation

The second rotation points the once-rotated x-axis along the sensor boresight vector by a rotation about the once-rotated y-axis. The magnitude of this angle is the pitch, or a deflection from the local horizon. This is illustrated in Figure 6. This angle is positive in the up-direction, where the blue-axis (once-rotated z-axis) moves towards the red-axis (once-rotated x-axis). Angle *A2* is equivalent to the sensor pitch and has a negative value.

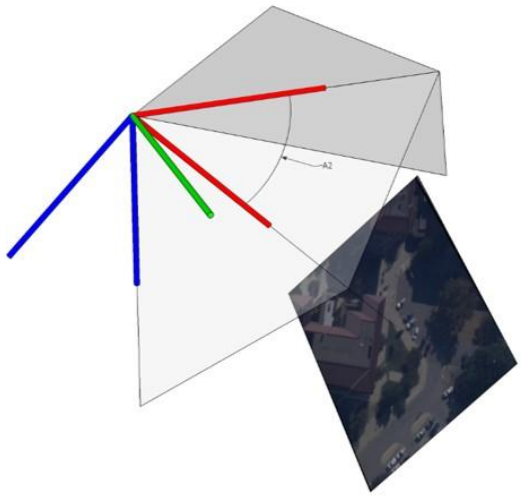

Figure 6: Description of the pitch rotation

The final rotation rotates the image about the sensor boresight vector by a rotation about the twice-rotated x-axis, which is illustrated in Figure 7. This magnitude of this angle is the roll of the sensor, where it is positive clockwise when looking from the sensor along the boresight vector; in other words, the green-axis (y-axis) moves towards the blue-axis (twice-rotated z-axis). Angle *A1* is equivalent to the roll angle.

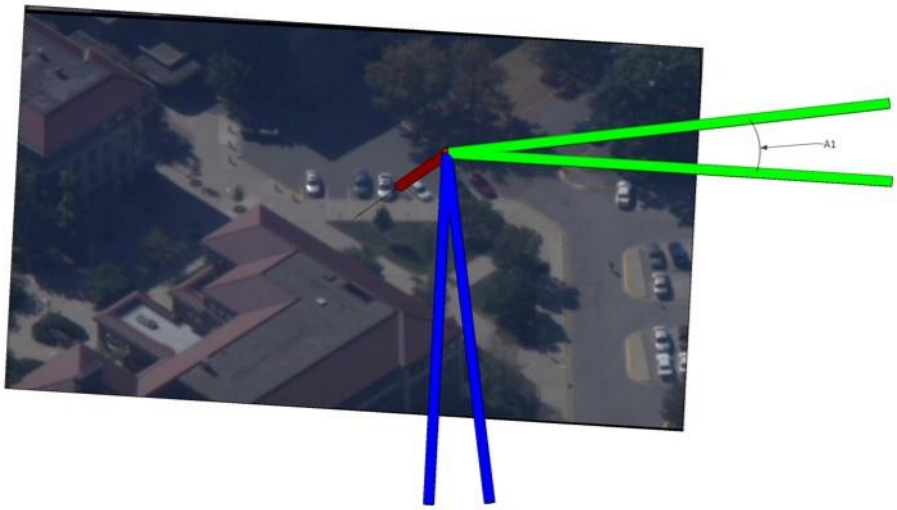

Figure 7: Description of the roll rotation

These rotations align the NED axes parallel to the Reference Axes. Equation 4 describes the total rotation matrix from the NED to the Inertial Measurement Unit (IMU) coordinate system. The IMU coordinate system represents the coordinate system for the senor's Reference Axes.

$$R_{NED}^{IMU} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos Ro & \sin Ro \\ 0 & -\sin Ro & \cos Ro \end{bmatrix} \begin{bmatrix} \cos Pt & 0 & -\sin Pt \\ 0 & 1 & 0 \\ \sin Pt & 0 & \cos Pt \end{bmatrix} \begin{bmatrix} \cos Az & \sin Az & 0 \\ -\sin Az & \cos Az & 0 \\ 0 & 0 & 1 \end{bmatrix}$$ **Equation 4**

The values used in this equation for the Azimuth (*Az*), Pitch (*Pt*), and Roll (*Ro*) angles can be derived from any rotation matrix that aligns an NED coordinate system with an IMU coordinate system. These values will be consistent no matter how the initial rotations were defined as long as the following prescription is followed. The rotation matrix is refined in Equation 5 through Equation 8 with each of its nine elements labeled.

$$R_{NED}^{IMU} = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix}$$ **Equation 5**

$$Az = \arctan\left(\frac{r_{12}}{r_{11}}\right)$$ **Equation 6**

$$Pt = \arcsin(-r_{13})$$ **Equation 7**

$$Ro = \arctan\left(\frac{r_{23}}{r_{33}}\right)$$ **Equation 8**

Using this formulation to define the angles allows the data provider to use *any* method of computing the rotation matrix that rotates the NED to the IMU coordinate system without loss of generality. In other words, this formulation does not have any underlying assumptions that will cause a loss in computational accuracy.

An additional computational note is dealing with the arctangent functions. Since the data collected for the azimuth and roll angles can be in all four quadrants of the unit circle, the two-argument form of the arctangent function (ATAN2) should be applied. Since the goal of this type of decomposition is to obtain an identical rotation matrix, the results of the previously described algorithm satisfy this objective; however, the actual values for the azimuth-pitch-roll may be different. The difference usually occurs when the pitch angle is less than -90 degrees or greater than +90 degrees. This condition will cause the azimuth to read 180 degrees different from the original angle, and the roll angle will also read 180 degrees different to account for the direction change. Again, the ATAN2 version of the decomposition will return identical results for the reconstructed rotation matrix. There is a possible discontinuity if the goal is to reconstruct the actual angles. Additional information is needed in order to determine the exact angles (*e.g.* adjacent frames or trajectory information).

Similarly, the rotation matrix for the boresighting offset angles that rotates the IMU coordinate system to the line-of-sight (Principal) coordinate system is formed using an identical sequence of rotations that rotate the NED system to the IMU system. This rotation matrix is described by Equation **9**Equation 9.

$$R_{IMU}^{LOS} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\beta_1 & \sin\beta_1 \\ 0 & -\sin\beta_1 & \cos\beta_1 \end{bmatrix} \begin{bmatrix} \cos\beta_2 & 0 & -\sin\beta_2 \\ 0 & 1 & 0 \\ \sin\beta_2 & 0 & \cos\beta_2 \end{bmatrix} \begin{bmatrix} \cos\beta_3 & \sin\beta_3 & 0 \\ -\sin\beta_3 & \cos\beta_3 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$ **Equation 9**

The order of rotations is applied similarly to the rotations from the NED to IMU rotations. The previously described Figure 5 through Figure 7 similarly describe the rotation of the IMU to line-of-sight coordinate systems.