MISB Motion Imagery Standards Board	**MISB ST 1002.1**
STANDARD	
Range Motion Imagery	**24 February 2014**

1 Scope

This Standard describes Range Motion Imagery, its format and supporting metadata.

Range Motion Imagery is a temporal sequence of Range Images. Each Range Image is a collection of Range Measurements from a sensor to target scene. A Range Measurement is the distance (e.g. meters) from an object (or area) in the scene to the sensor. The KLV structures of this Standard are intended to allow for flexibility, efficient packing, and future extensions. Range Motion Imagery can be used standalone or in collaboration with other Motion Imagery. MISB ST 1107 Metric Geopositioning Metadata Set [13] provides the basis for collaborating with other Motion Imagery types.

This Standard describes the: Perspective Range Motion Imagery and Depth Range Motion Imagery; the collection methods of Range Motion Imagery; the formats used for storing or transmitting Range Motion Imagery; the supporting metadata needed for Range Motion Imagery including, temporal, uncertainty and compression parameters; and the alignment to Collaborative Imagery.

2 References

2.1 Normative Reference

[1] MISB ST 0107.2, Bit and Byte Order for Metadata in Motion Imagery Files and Streams, Feb 2014
[2] ISO/IEC, 8825-1:2008 (ITU-T X.690) Information Technology – ASN.1 Encoding Rules - BER-OID Sub-Identifier defined in Section 8.19.2
[3] MISB ST 1303 Multi-Dimensional Array Pack, Feb 2014
[4] MISB ST 1201.1 Floating Point to Integer Mapping, Feb 2014
[5] MISB ST 0603.2 Common Time Reference for Digital Motion Imagery Using Coordinated Universal Time (UTC), Feb 2014
[6] MISB ST 1202.1 Generalized Transformation Parameters, Feb 2014
[7] SMPTE RP 210v13:2012 Metadata Element Dictionary
[8] MISB ST 0807.13 MISB KLV Metadata Dictionary, Feb 2014
[9] SMPTE ST 336:2007 Data Encoding Protocol Using Key-Length-Value
[10] MISB RP 0701 Common Metadata System, August 2007

2.2 Informative References

[11] Mikhail, Edward M., James S. Bethel, and J. Chris McGlone. Introduction to Modern Photogrammetry. New York: John Wiley & Sons, Inc., 2001

[12] MISB ST 1010.1 Generalized Variance and Covariance Matrix Metadata Type, Feb 2014

[13] MISB ST 1107.1 Metric Geopositioning Metadata Set, Feb 2014

3 Modifications and Changes

Revision	Date	Summary of Changes
1002.1	02/27/2014	• Changed from Engineering Guideline to Standard. • ST 1002 now defines Range Imagery as Range Motion Imagery (an Motion Imagery essence) • Using Multidimensional Arrays for formatting Range Images (ST 1303) • The enumeration table was expanded • The enumeration for height data was eliminated due to the complexity of the uncertainty propagation required. • An improved error checking method is now used. • Additional sections were added to the appendix to give detained descriptions on the Projective Transformation and the Accuracy Model Description. • Applied ST 1202 Generalized Transformation Parameters • Added Depth Imagery Capabilities

4 Definitions and Acronyms

KLV	Key-Length-Value
Local Set	Local Set
MISB	Motion Imagery Standards Board
ST	Standard
SMPTE	Society of Motion Picture and Television Engineers
VLP	Variable Length Pack

5 Introduction

Range Motion Imagery is a series of Images where the value of the Range Image Pixels is the distance from the Sensor to a Scene Area. There are two primary types of Range Imagery and multiple sources of Range Imagery that are discussed in the following sections.

5.1 Range Imagery Types

Range Imagery data values can represent two different types of measurements: **Perspective Range Measurements** or **Depth Range Measurements**. **Perspective Range Measurements** represent measured or computed distances from the Scene Areas to the perspective center of the sensor, as shown in Figure 1.

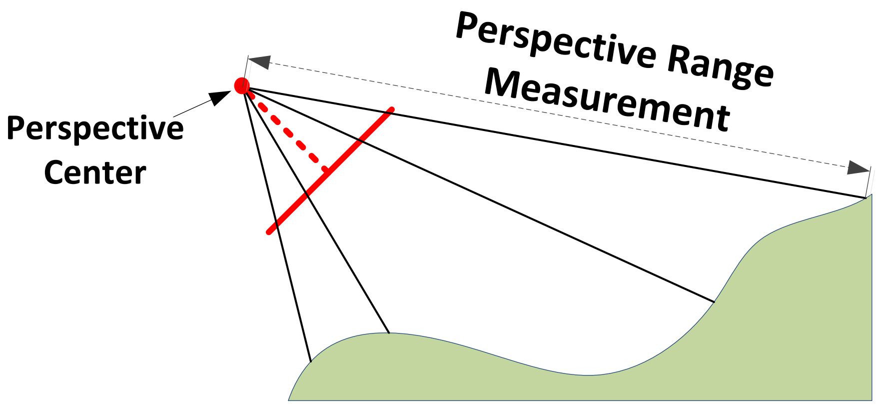

Figure 1: Illustration of Range Measurements (profile view)

Perspective Range data can be directly integrated with a rigorous sensor model without any further processing.

Depth Range Measurements represent measured or computed distances from the Scene Areas to a plane parallel to the focal plane, as shown in Figure 2. For this standard the plane parallel to the focal plane will be called the Backplane.

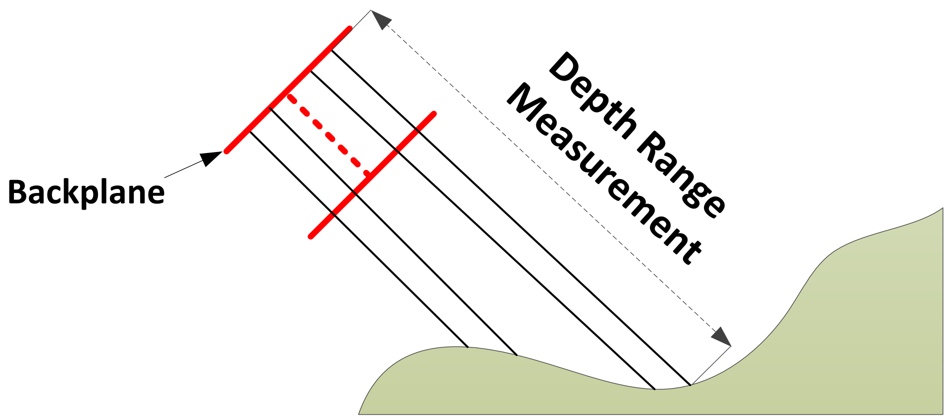

Figure 2: Illustration of Depth Range Measurements (profile view)

Depth data is also more commonly known as depth fields or depth maps. Although depth data cannot be integrated into a rigorous sensor model, depth data can be converted to range data; however, the algorithm for this processing is not defined in this version of this Standard.

5.2 Range Imagery Sources

Range Imagery may be collected directly from a **Range Sensor** or **Computationally Extracted** from another imagery source (e.g. Camera) or data source (e.g. Point Cloud).

5.2.1 Range Sensor

When the Range Imagery is collected directly from a **Range Sensor** it can be either stand-alone or related to another Sensor, called a Collaborative Sensor. Examples of Collaborative Sensors are Visible Light or IR cameras. When the Range Imagery is related to a Collaborative Sensor it is either co-boresighted or non-boresighted with the Collaborative Sensor. Co-boresighted Range Imagery is when the sensor collects data through the same physical aperture as a Collaborative Sensor, and it provides identical geometry to the Collaborative Sensor's collected image; Figure 3 illustrates a co-boresighted system. Although the geometry is the same the Range and Collaborative Images may not have the same orientation, pixel sizes or magnification through the optical path. These effects can be modeled using the Generalized Transformation (ST1202 [6]) which is a mathematical process that maps the data from one image perspective to another. The parameters from the Generalized Transformation can be included with the Range data for later processing.

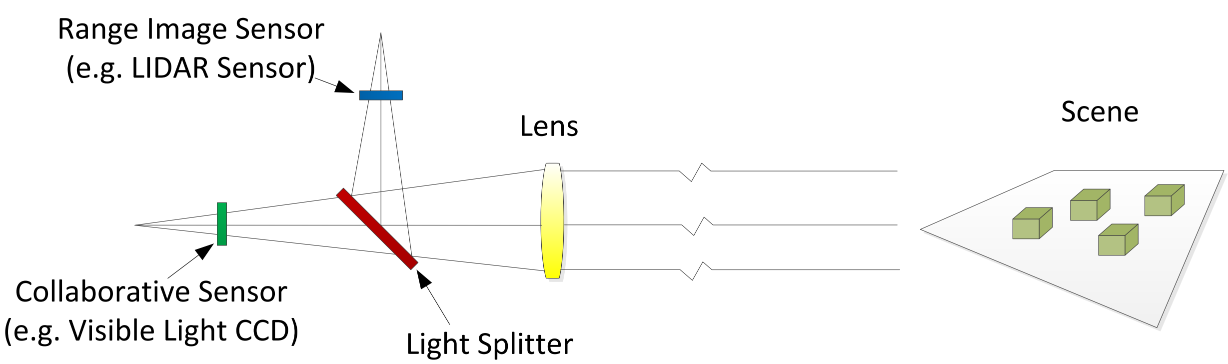

Figure 3: Illustration of a co-boresighted System of Sensors

If the Range Imagery does not meet the requirements for being co-boresighted then the Range Imagery is called non-boresighted and a transformation is needed to align the Range Imagery with the Collaborative Imagery. Figure 4 illustrates a non-boresighted system of Sensors.

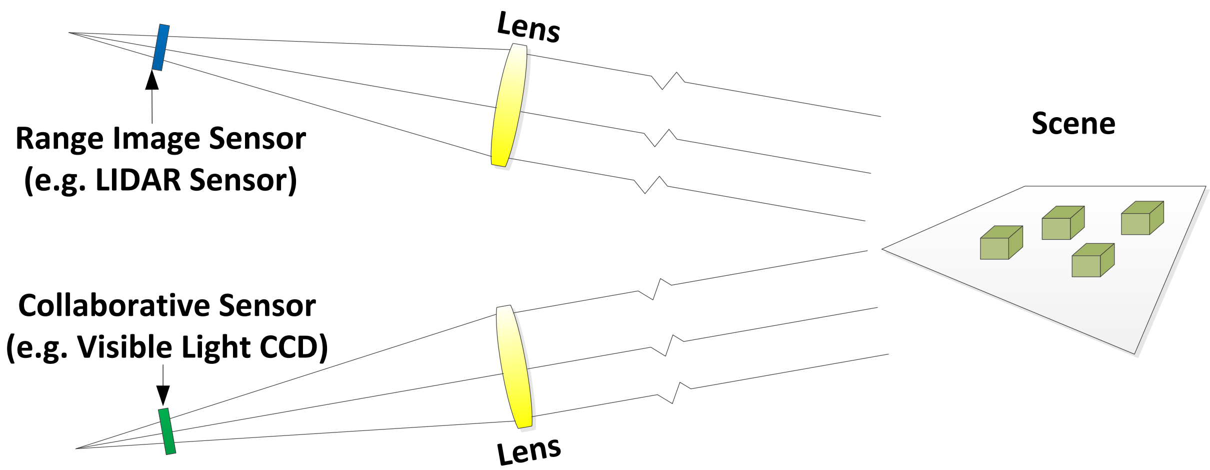

Figure 4: Non-Boresighted System of Sensors

The transformation is a mathematical process that maps the data from one image perspective to another; the transformation is discussed in ST 1202 [6].

5.2.1.1 Single Point Range Measurement

When the Range Imagery is being used with Collaborative Sensors, the Range Image dimensions (lines and pixels) may not be the same as the as the Collaborative Sensor. A Range Image can be under or oversampled compared to the Collaborative Sensor's Image. The minimum size of the Range Image can be as small as one range measurement which is a special case of the Range Image data, called a Single Point Range Measurement.

A Single Point Range Measurement is associated with a Collaborative Sensor's Image. The Single Point Range Measurement is a measurement that starts from either the perspective center or Backplane of the Collaborative Sensor through the image plane to a point on the scene. Because the Single Point Range Measurement may not be in the exact center of the Collaborative Sensor's frame, the line and sample location of the image intersection pixel is also part of this measurement. When the Single Point Range Measurement passes through the center pixel of the image, then the range measurement is called a Single Aim Center Pixel Range Measurement or SACP Range Measurement. Figure 5 and Figure 6 illustrate a Single Point Range Measurement and a SACP Range Measurement. The illustrations show the Single Point Range Measurements as Perspective Range Measurements; however the Single Point Range Measurements can also be Depth Range Measurements.

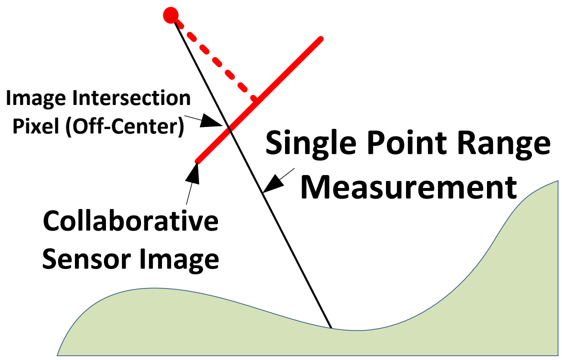

Figure 5: Single Point Range Measurement

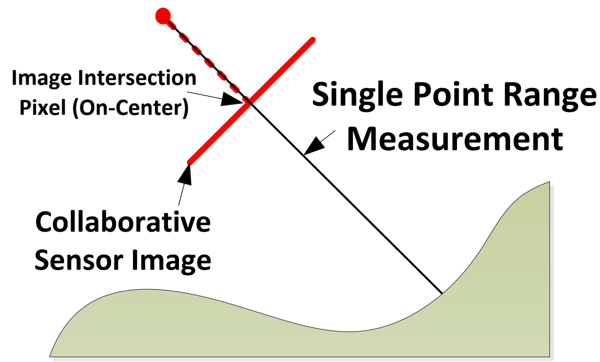

Figure 6: Single Point Range Measurement that is also a Single Aim Center Pixel Range Measurement

5.2.2 Computationally Extracted

Computationally Extracted Range Imagery is an alternative to active sensor measuring; computational extracted means inferring the range data from optical flow or other image/data processing techniques.

5.3 Range Imagery Data Uncertainty

Since Range Imagery is a set of measured or computed distances there are errors associated with these distance values. To provide the most utility of the Perspective Range or Depth Range data this document includes the formatting method for the uncertainty of the Range Imagery at each pixel in the range image. The uncertainty is computed, estimated or measured (or a combination of the three) by the sensor developer. The uncertainty is system's ability to measure range reliable and varies for each ranging system. The Range Measurement uncertainty is expressed as a standard deviation (sigma, σ_i) in meters along the Range Measurement vector.

6 Range Motion Imagery Data Representation

The Range Image Data Representation has two use cases: **Range Image** and **Single Point Range Measurement**. When formatting a **Range Image,** a two dimensional frame of data along with its uncertainty, transformation information and support values are packaged together. Alternatively, when transmitting **Single Point Range Measurement (**see Section 5.2.1.1), a single Range value along with its uncertainty, line and pixel locations are packaged together.

Range Motion Imagery is a series of Range Images (or Single Point Range Measurements) with each Range Image formatted using KLV in a Local Set. The Range Motion Imagery Local Set contains different categories of data to support the two different use cases; these categories are listed in Table 1.

Table 1: Categories of data included in Range Motion Imagery Local Set

Category	Description
Administration	Administrative Information for the Local Set (i.e. Version number and CRC). Required in all use cases.
Support	Information for describing the Range Motion Imagery (e.g. Image Time, Range Imagery Type, etc.). Required for all use cases.
Single Point Range	Information for describing and supporting the Single Point Range Measurement use case.
Range Image	Information for describing and supporting the Range Image Data use case.

The items contained in the Range Motion Imagery Local Set are listed in Table 2, which has the following columns:

- Tag ID is the Local Set tag to use for that value
- Key lists the KLV Dictionary Key for that item, either in SMPTE RP 210 [7] or MISB ST 0807 [8].
- Name contains the name of the dictionary element from the viewpoint of this document along with the official name from the KLV dictionary (in parenthesis) if the names are different.
- Category determines the purpose or use case of the data item and the section number for the full description.
- Data Type is the type of data for the element. VLP = Variable Length Pack

Additionally, “Single Point Range Measurement” is abbreviated as SPRM in this table.

Table 2: Range Image Local Set

Tag ID[1]	Key	Name (KLV Dictionary Name)	Category	Data Type
1	06.0E.2B.34.01.01.01.03. 07.02.01.01.01.05.00.00 (CRC 64827)	Range Image Frame Time (POSIX Microseconds)	Support (6.2.1)	UINT64
11	06.0E.2B.34.01.01.01.01. 0E.01.02.05.05.00.00.00 (CRC 56368)	Version	Administration (6.1.1)	BER-OID
12	06.0E.2B.34.01.01.01.01. 0E.01.02.03.60.00.00.00 (CRC 62498)	Range Image Enumerations	Support (6.2.2)	BER-OID
13	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3E.04.00.00 (CRC 12643)	SPRM (Range Measurement)	Single Point Range (6.3.1)	FLOAT
14	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3E.05.00.00 (CRC 1619)	SPRM Uncertainty (Range Measurement Uncertainty)	Single Point Range (6.3.2)	FLOAT
15	06.0E.2B.34.01.01.01.01. 0E.01.02.05.07.00.00.00 (CRC 12632)	SPRM Line Coordinate (Measured Line Coordinate for Range)	Single Point Range (6.3.3)	FLOAT
16	06.0E.2B.34.01.01.01.01. 0E.01.02.05.08.00.00.00 (CRC 58806)	SPRM Sample Coordinate (Measured Sample Coordinate for Range)	Single Point Range (6.3.3)	FLOAT
17	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3E.00.00.00 (CRC 60835)	Number of Sections in X	Range Image (6.4.2)	BER-OID
18	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3E.01.00.00 (CRC 55955)	Number of Sections in Y	Range Image (6.4.2)	BER-OID
19	06.0E.2B.34.02.0B.01.01. 0E.01.03.05.05.00.00.00 (CRC 40498)	Generalized Transformation Local Set	Range Image (6.4.3)	Local Set
20	06.0E.2B.34.02.04.01.01. 0E.01.03.03.01.00.00.00 (CRC 4725)	Section Data Variable Length Pack	Range Image (6.4.1)	VLP
21	06.0E.2B.34.01.01.01.01. 0E.01.02.03.5E.00.00.00 (CRC 31377)	CRC-16-CCITT	Administration (6.1.2)	UINT16

[1]There are some Tag ID's that have been deprecated from the Local Set because they were used in an earlier version that has now been replaced by this version. If new items are added to this set do NOT use the following tag ids: 2, 3, 4, 5, 6, 7, 8,9,10, 51, 52, 53, or 54.

The Range Image Local Set has the following data formatting requirements.

Requirement	
ST 1002.1-01	The Range Image Local Set shall have the UL Key 06.0E.2B.34.02.0B.01.01.0E.01.03.03.0C.00.00.00 (CRC 41152)
ST 1002.1-02	All metadata shall be expressed in accordance with MISB ST 0107 [1].

6.1 Administrative Information

There are two Administrative Information items in the Range Image Local Set, **Version Number** and **CRC Error Detection**.

6.1.1 Version Number

The **Version Number** of the Local Set is the same as the minor version number of this document. For example, with ST 1002.1, the version number value would be '1', with ST 1002.2; the version number value would be '2', etc.

Requirement	
ST 1002.1-03	Range Image Local Sets shall include a Version Number

All Range Imager Local Set parsers should validate the version number to ensure that the parser is properly parsing the local set and the Data Section Variable Length Pack (defined in Section 6.4.1).

6.1.2 CRC Error Detection

To help detect erroneous metadata after transmission, a 2-byte **CRC** is included in the Local Set as the last item. The CRC is computed across the entire Local Set packet starting with the 16-byte Local Set key and ending with the length field of the CRC data element. Figure 7 illustrates the data range the checksum is performed over.

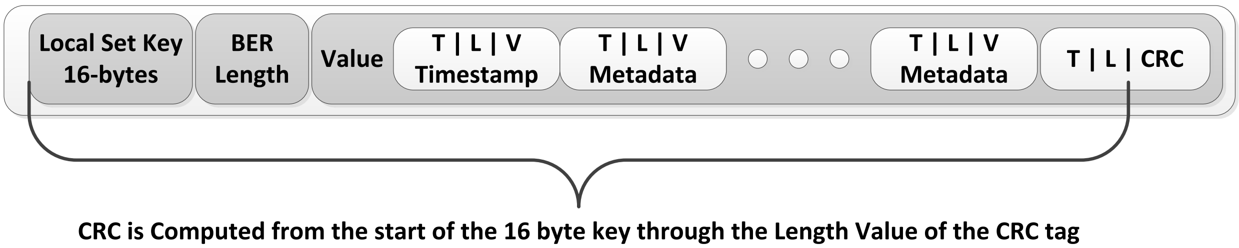

Figure 7: Bytes included in the CRC computation

If the calculated CRC of the received Local Set packet does not match the CRC stored in the packet, the packet is discarded as being invalid.

Requirement	
ST 1002.1-04	Range Image Local Sets shall have a CRC computed and included in accordance with ST 1002.1

Refer to MISB RP 0701 [10], Appendix C for details and sample code for computing the CRC.

6.2 Range Motion Imagery Support Data

Range Motion Imagery requires support data to properly interpret the Range Imagery; there are two Support Data Items in the Local Set: Range Image Frame Time and Range Encoding Enumerations.

6.2.1 Range Image Frame Time

The Range Image Frame Time is the time that is associated with the middle of integration of the Range Image. This time information is used to coordinate the Range Image with other sources of data, such as a collaborative sensors image or other sensor data. The time value is a 64 bit unsigned integer value which represents the number of microseconds since midnight of January 1st 1980 as defined in MISB ST 0603 [5].

Requirement	
ST 1002.1-05	A Range Image Local Set shall always include a Precision Timestamp (MISB ST 0603) tag.
ST 1002.1-06	The Precision Timestamp tag shall appear as the first metadata item within an Local Set.

Positioning the Precision Timestamp tag as the first item of the Local Set enables a rapid check on whether the local set matches the desired time for processing a collaborative frame.

6.2.2 Range Image Enumerations

The Range Image Enumerations is an integer value where the bits of the integer contain one or more enumerated values. To enable possible future extension this value is formatted as a BER-OID sub-identifier so before the number is interpreted it needs to be converted into a standard integer, see [2] for further information. As shown in Table 3, the Range Image Enumerations contains three separate enumerated values: **Range Image Source**, **Range Image Data Type**, and **Range Image Compression Method**.

Range Image Source declares how the Range Imagery was created, either from a Range Sensor or Computationally Extracted, as described in Section 5. This enumeration has two values so it consumes one bit of the Range Imager Enumerations value.

Range Imagery Data Type declares the type of Range Imagery, either Perspective Range Image or Depth Range Image, as described in Section 5. To allow for further types to be defined in the future this enumeration will have eight values (0 through 7) where currently only two values are defined: 0=Perspective Range Image and 1=Depth Range Image.

Range Imagery Compression Method declares the method of compression used for reducing the number of bytes of the Range Image. There is one method of compression called Planar Fit that is described in Section 7. To allow for further compression techniques to be defined in the future this enumeration will have eight values (0 through 7) where currently only two values are defined: 0=No Compression and 1=Planar Fit.

The Range Image Enumeration value is the combination of the Range Image Source, Range Imagery Data Type, and the Range Imagery Compression Method. The least significant 7 bits of the Range Imagery Enumeration value are shown in Table 3.

Table 3: Range Image Enumerations

MSB ← Bits → LSB						
6	5	4	3	2	1	0
Range Image Source	Range Imagery Data Type			Range Imagery Compression Method		
0 = Computationally Extracted 1 = Range Sensor	000 = Perspective Range Image 001 = Depth Range Image 010 - 111 = Reserved			000 = No Compression 001 = Planar Fit 010 - 111 = Reserved		

When the Range Image Enumeration value is formatted into BER-OID the eighth most significant bit, which is equal to zero (0), is added. It is possible that this value could grow to two or more bytes in future versions of this Standard, in which case the BER-OID parsing rules would be used, see [2] for further information. When two or more bytes are used the least significant byte will always be parsed as described in Table 3; all future additions will add more significant bytes and bits.

6.3 Single Point Range Measurements

Single Point Range Measurements are one use case of the Range Image Local Set. Single Point Range Data is composed of the Single Point Range Measurement, Single Point Range Measurement Uncertainty and Single Point Range Measurement Line and Sample Coordinates.

6.3.1 Single Point Range Measurement

The Single Point Range Measurement is the measure of distance (in meters) from either the principle point or Backplane of a Collaborative Sensor through the image plane to a point in the scene; see 5.2.1.1. This value is a can be either a 32 bit or 64 bit IEEE floating point value.

6.3.2 Single Point Range Measurement Uncertainty

The Single Point Range Measurement Uncertainty is the uncertainty (sigma,σ) of the Single Point Range Measurement data, in meters, along the measured vector from either the perspective center or Backplane to the scene. This value is a can be either a 32 bit or 64 bit IEEE floating point value. The uncertainty is determined by the implementing system and must follow the guidelines in Section 5.3.

6.3.3 Single Point Range Measurement Line and Samples Coordinates

The Single Point Range Measurement is not necessarily measured directly through the center of the Collaborative Image; therefore, the location within the image needs to be indicated. The Single Point Range Measurement Line and Sample Coordinates are the coordinates within the Collaborative Sensor's Image where the measurement was taken (see Section 5.2.1.1). These values are BER-OID Subidentifier values. If the Line and Sample values are omitted from the Range Image Local Set then the default values are set to the center of the Collaborative Sensors Image.

Requirement	
ST 1002.1-07	When Single Point Range Measurement Line Coordinate is not included in the Range Image Local Set, then the default value shall be set to the center line of the image.
ST 1002.1-08	When Single Point Range Measurement Pixel Coordinate is not included in the Range Image Local Set, then the default value shall be set to the center pixel of the lines used in the image.

6.4 Range Image

Range Images are one use case of the Range Imagery Local Set; Range Images are used when more than one range measurement is obtained. A Range Image is an array of Range Measurements each of which is the measure of the distance (in meters) from either the principle point or Backplane to a point in the scene; see Section 5.2.1.1. The Range Image is formatted as a two dimensional array of data for a given time period (see Section 6.2.1).

Range Imagery Data is a rectangular array of Range Measurements as described in Section 5.1. Range Imagery Data can be formatted in whole or in separate parts, where each part is called a Section. Sections are rectangular areas that when combined together form the full frame. Each Section can be compressed to provide the most efficient transmission and storage. Sections have two different layouts, **simple** or **complex**. A **simple** Section layout divides the image into either horizontal or vertical strips. All horizontal strips have the same width as the full image but can vary in height as needed as illustrated in Figure 8. All vertical strips have the same height as the full image but can vary in width as illustrated in Figure 9.

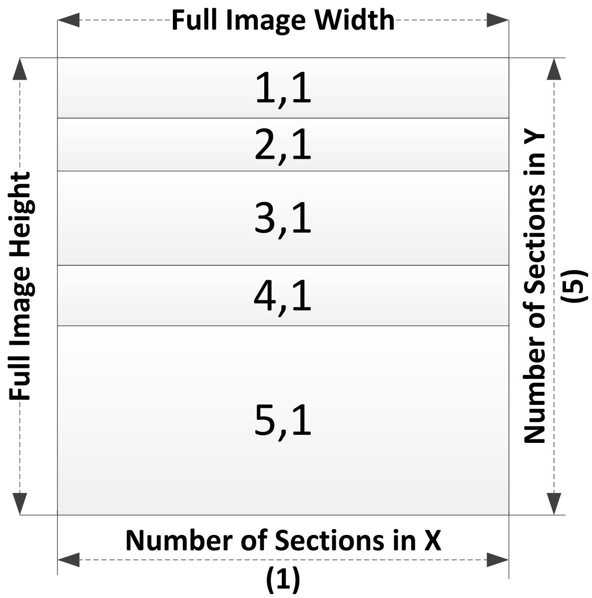

Figure 8: Illustration of five Horizontal Strips

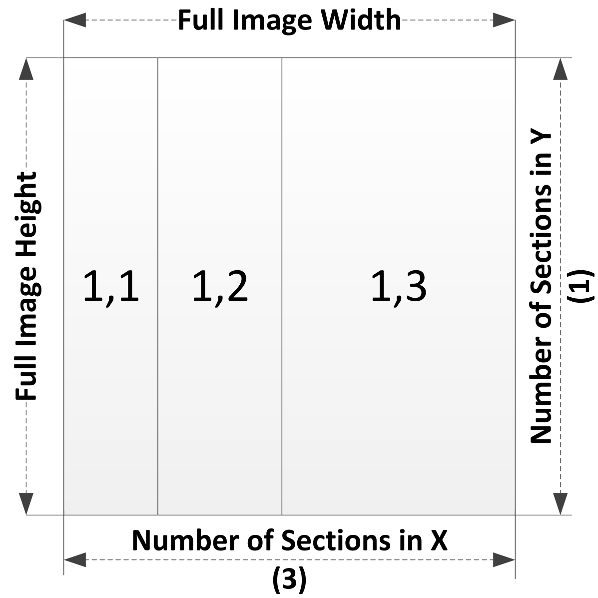

Figure 9: Illustration of three Vertical Strips

A **complex** Section layout divides the image into various size rectangles where each rectangle does not necessarily span the full image width or height as illustrated in Figure 10.

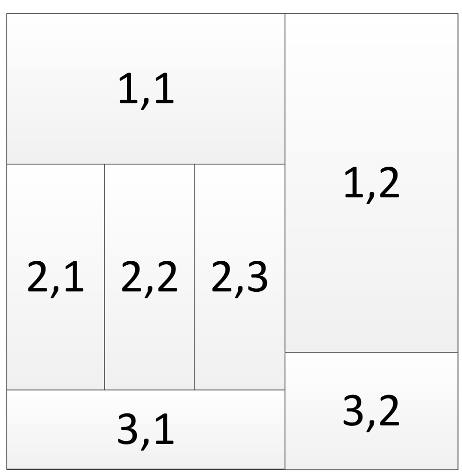

Figure 10: Illustration of Complex Section layout

Currently, this Standard only allows simple Section layout; however complex Section layout may be allowed in the future.

Requirement	
ST 1002.1-09	Range Images shall only be formatted using the Simple Section layout method.

When the Range Image is formatted into separate Sections the Range Image Local Set will contain multiple Section Data Variable Length Packs. Specifically, there number of Section Data Variable Length Packs will be Number of Sections in X times Number of Sections in Y.

The Range Image use case includes additional Range Image parameters to help compress and interpret the Range Image. The Range Image use case consists of the Section Data, Number of Sections in X and Y, and Generalized Transformation data.

6.4.1 Section Data Variable Length Pack

Section data, along with its supporting information is formatted in a Variable Length Pack (VLP) (see SMPTE 336 [9]) called the Data Section VLP. The information in each Data Section VLP includes the required Section coordinates, the Section data array, the Section data uncertainty values, and optional compression parameters. The optional compression parameters are truncated from the VLP (along with their lengths) as a group (in a similar fashion to RP 0701 Floating Length Packs). Figure 11 illustrates a Data Section VLP with each item in the VLP prefixed with its item length. The green items show the required values (along with their lengths in blue), the pink item can be "zero-ized" (see Section 6.4.1.3) and the yellow items can be truncated (along with their lengths).

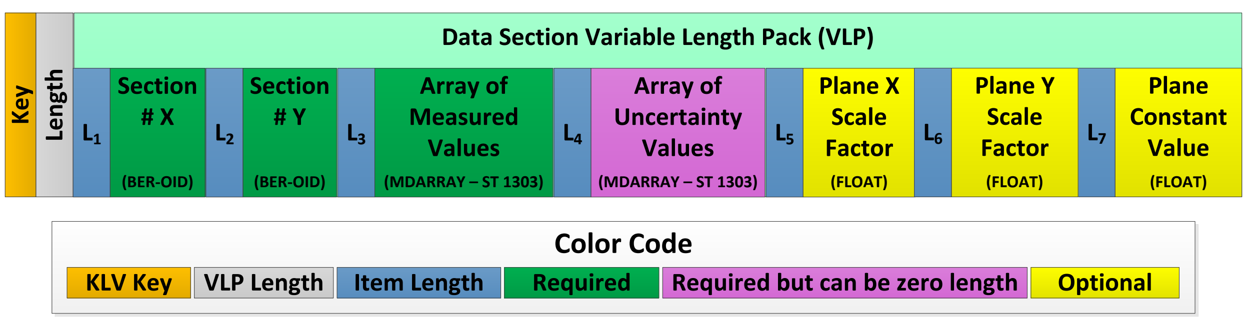

Figure 11: Illustration of Data Section Variable Length Pack

The items contained in the Data Section VLP are listed in Table 4, which has the following columns:

- Key lists the KLV Dictionary Key for that item, either in SMPTE RP 210 [7] or MISB ST 0807 [8].
- Name contains the name of the dictionary element from the viewpoint of this document along with the official name from the KLV dictionary (in parenthesis) if the names are different.
- Notes provides additional information about the value

- Format lists the data type used for the value
- RZO shows if the value is Required, Zeroizable or Optional.

Table 4: Data Section Variable Length Pack (VLP)

Key	Name	Symbol/Notes	Format	RZO
06.0E.2B.34.01.01.01.01. 0E.01.01.03.3E.02.00.00 (CRC 33731)	Section Number X	Coordinates of the Section within the full image	BER-OID	R
06.0E.2B.34.01.01.01.01. 0E.01.01.03.3E.03.00.00 (CRC 46323)	Section Number Y		BER-OID	R
06.0E.2B.34.02.05.01.01. 0E.01.03.03.06.00.00.00 (CRC 39697)	Array of Range Measurements	Formatted in ST1303 (Includes dimensions, and IMAPB parameters)	MDARRAY(See Section 6.4.1.2)	R
06.0E.2B.34.02.05.01.01. 0E.01.03.03.06.00.00.00 (CRC 39697)	Array of Uncertainty Values	Formatted in ST1303 (Includes dimensions, and IMAPB parameters)	MDARRAY(See Section 6.4.1.3)	Z
06.0E.2B.34.01.01.01.01. 0E.01.02.02.81.2D.00.00 (CRC 26810)	Plane X-scale Factor	a in Equation 8	Float 32 or Float 64	O
06.0E.2B.34.01.01.01.01. 0E.01.02.02.81.2E.00.00 (CRC 12778)	Plane Y-scale Factor	b in Equation 8	Float 32 or Float 64	O
06.0E.2B.34.01.01.01.01. 0E.01.02.02.81.2F.00.00 (CRC 1754)	Plane constant value	c in Equation 8	Float 32 or Float 64	O

6.4.1.1 Section Coordinates

The Section Coordinates define the location of where, in the full frame data, the Section belongs. Section numbers always start in the upper left of the full frame and increment towards the lower right. With simple Section Layouts one of the Section Coordinates will always be one. For example, Figure 8 shows five sections, when sending the bottommost Section the Section Number X would equal 1 and Section Number Y would equal 5. In order to reassemble the full frame all Sections need to be assembled in order, from the lowest value X/Y Section Coordinates to the largest X/Y Section Coordinates. The Section Number X and Y values are encoded as BER-OID sub-identifier values so that they can accommodate any Section size.

Requirement	
ST 1002.1-10	Data Section Variable Length Packs shall always contain Section Number X and Section Number Y.
ST 1002.1-11	One of the Section Coordinate Values, either Section Number X or Section Number Y, shall always be one.
ST 1002.1-12	When reassembling a full frame all Sections shall be assembled in order from the lowest value X/Y Section Coordinates to the largest X/Y Section Coordinates.

6.4.1.2 Array of Range Measurements

The Array of Range Measurements contains either the original range measurements or the adjusted range measurements that are produced from the plane subtraction processing, see Section 7. When the array contains the adjusted range measurements they are computed using Equation 9. In order to reverse the computations the compression parameters are used from Section 6.4.1.4.

The array is formatted using MISB ST1303 [3] and optionally includes the ST 1201 IMAPB Float-to-Integer min, max values. The ST 1303 MDARRAY parameters for the Data Array are:

MDARRAY(06.0E.2B.34.01.01.01.01.0E.01.01.03.3E.04.00.00 (CRC 12643), 2, Note_A, Note_A, Note_B, Note_C, Note_C)

Note_A: This value is system dependent (i.e. dependent on the size of the sensor); the system provider specifies the proper size.

Note_B: The Element Size is based on whether the system provider is formatting the data as floating point values or packing the values using IMAPB. When using floating point values the Element Size will be either 4 or 8 bytes. When using IMAPB the system provider specifies the appropriate precision for the system along with the minimum and maximum values of the array (see Note_C) to compute the appropriate Element Size.

Note_C: The Min and Max values are determined by the bounds of the array data before mapping is applied. For Plane Subtraction the Min, Max values are computed after the Plane Subtraction has been performed.

The Range Image Data has a reserved item to represent the Not-a-Number (NaN) value. The integer representation of values with reserved bits is described in MISB ST 1201 [4]. The NaN signifies that no reliable range information exists at a particular pixel within the range image.

6.4.1.3 Array of Uncertainty Values

The Array of Uncertainty Values is formatted using MISB ST 1303 and optionally includes the IMAPB min, max values.

Requirement	
ST 1002.1-13	The number of elements in the Data Section VLP - Array of Uncertainty Values shall match the number of elements in the Array of Measured Values.

The ST 1303 MDARRAY parameters for the Uncertainty Array are:

MDARRAY(06.0E.2B.34.01.01.01.01.0E.01.01.03.3E.05.00.00 (CRC 1619), 2, $Note_D$, $Note_D$, $Note_E$, $Note_F$, $Note_F$)

$Note_D$: This value is system dependent (i.e. dependent on the size of the sensor); the system provider determines the proper size. This value must match the Data Array value in Section 6.4.1.2 - $Note_A$.

$Note_E$: The Element Size is based on whether the system provider is formatting the data as floating point values or packing the values using IMAPB. When using floating point values the Element Size will be either 4 or 8 bytes. When using IMAPB the system provider specifies the appropriate uncertainty precision for the specific system along with the minimum and maximum values of the array (see $Note_C$) to compute the appropriate Element Size.

$Note_F$: The Min and Max values are determined by the bounds of the array data before mapping is applied; for uncertainty data the smallest Min value allowed is zero.

Requirement	
ST 1002.1-14	The smallest Min value for the Range Measurement Uncertainly data shall be zero (0).
ST 1002.1-15	If a Range Image does not have an array of uncertainty values, then the length for this Variable Length Pack item shall be set to zero.

The Range Image Uncertainty data has a reserved item to represent the Not-a-Number (NaN) value. The integer representation of values with reserved bits is described in MISB ST 1201 [4]. The NaN signifies that no reliable uncertainty information exists at a particular pixel within the range image.

When a Range Image does not have an array of uncertainty values then the length for this Variable Length Pack item is set to zero. When parsing a Data Section VLP, a zero length for the Array of Uncertainty Values indicates that there is not an uncertainty array “value” so the next item in the Data Section VLP is processed.

6.4.1.4 Compression Parameters

The compression parameters, which are optional, are values used to perform Plane Subtraction (see Section 7) on the Section data array. The plane subtraction is used to reduce the dynamic range of the Range Measurement values, therefore reducing the number of bytes needed to represent each value. Plane Subtraction is only performed on the Section Data array and does not apply to the Section Data uncertainty values. Plane Subtraction is performed by first computing a reference plane based on a two-dimensional least-squares estimate of a Section’s data, and then subtracting the reference plane from all of the range values in the Section. This process reduces a large dynamic range to a set of small ranges that can be further processed using the Floating Point to Integer Mapping that is referenced in MISB ST 1303. The plane subtraction technique is fully described in Section 7. Three compression parameters are specified: Plane X-scale (a in Equation 10), Plane Y-scale Factor (b in Equation 10), and Plane constant value (c in Equation 10). Each of these values is either a 32 or 64 bit IEEE floating point value.

6.4.2 Number of Sections in X and Y

The full Range Image (and Range Uncertainty) can be divided into parts, called Sections which can enable better Plane Subtraction algorithm performance. The Number of Sections in X is the count of sections in the X direction and the Number of Sections in Y is the count of sections in the Y direction. For this version of the Standard the only Section layout used is the simple Section layout so, either the Number of Sections in X or the Number of Sections in Y must be one as was illustrated in Figure 8 and Figure 9. For example in Figure 8, the Number of Sections in X equals one and the Number of Sections in Y equals five. In Figure 9 the Number of Sections in X equals 3 and the Number of Sections in Y equals 1. Each value is an unsigned integer, represented in BER-OID sub-identifier format. If the Number of Sections in X or Number of Sections in Y are not included in the Local Set then the values are defaulted to be one (1).

6.4.3 Generalized Transformation

The Generalized Transformation is a mathematical transformation that is used to project information, points, or lines from one image plane into a second image plane. The use of the Generalized Transformation Local Set is for the specific cases when aligning a Range Image to a Collaborative Sensors Image. In this case the Range Image is said to be a child of the Collaborative Image (i.e. the parent image).

The boresighted imaging case is a hardware solution, where multiple focal plane arrays are simultaneously imaging through a single aperture, see Section 5.2. This set-up of the hardware limits the variation in the perspective centers and the principal axis of the system to be coincident. Therefore, the three-dimensional scene is imaged on two dependent focal plane arrays, where the dependency is in the geometry. These focal planes do not necessarily have the same orientation or identical pixel sizes. Also, the magnification the two optical paths can be different causing different image scales. These effects can be sufficiently modeled using the Generalized Transformation.

The child-parent transformation parameters in the Generalized Transformation Local Set are defined in MISB ST 1202. The Value portion of the ST 1202 Local Set is directly inserted into the Range Image Local Set without any changes.

7 Plane Subtraction Compression

Range Images have a unique property that can be used to compress the amount of bytes that are used when transmitting or storing the data. Typically the surfaces of the scene are fairly regular so the Range Image data is relatively uniform (especially in a local area) and smooth. Figure 12 illustrates a Range Image of the ground from an airborne system. Unlike an optical image the

Range Measurements are fairly smooth. For example an optical image contains textures that have adjacent pixels that vary greatly in value (i.e. a white pixel next to a black pixel next to a red pixel, etc.), with Range Images the adjacent pixels are relatively close in value (i.e. 120 meters, next to 125 meters, next to 115 meters, etc.)

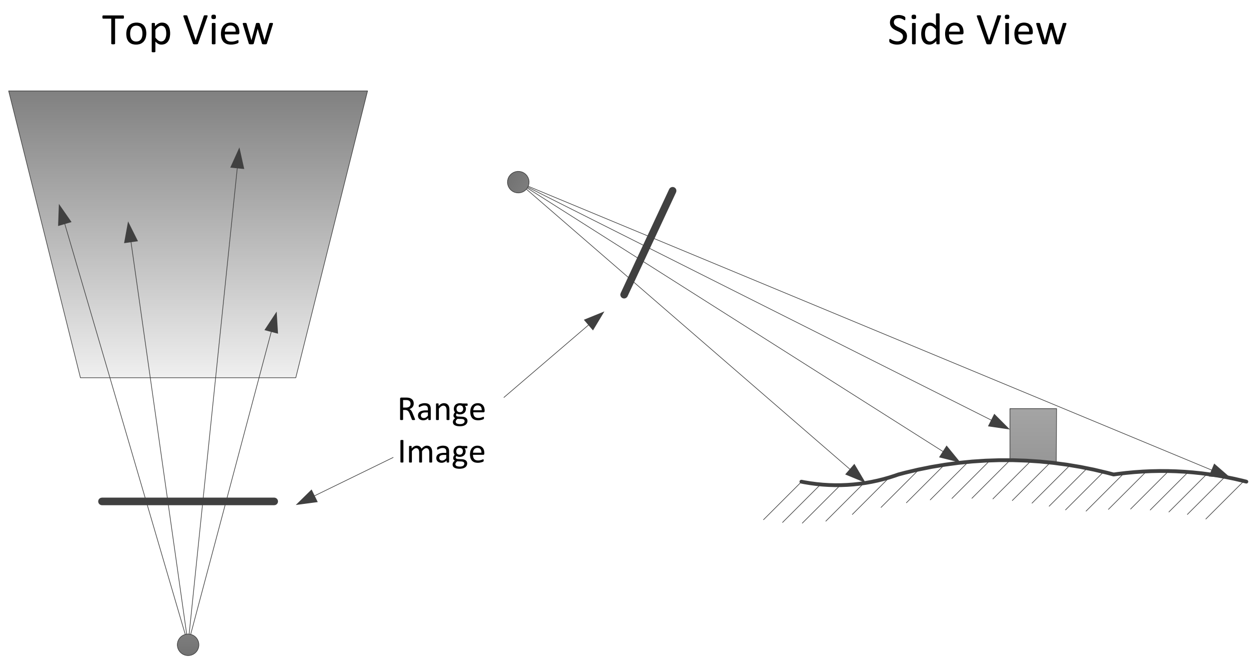

Figure 12: Illustration of Airborne Range Image

Because of this relative uniformity, the Range Measurements can be fitted to mathematical plane that can be subtracted from the original Range Image producing a residual image with much smaller numerical range. With a smaller numerical range the individual values require less bytes providing a level of compression over the original Range Image. A simplified example is a one-dimensional set of Range Data as shown Figure 13.

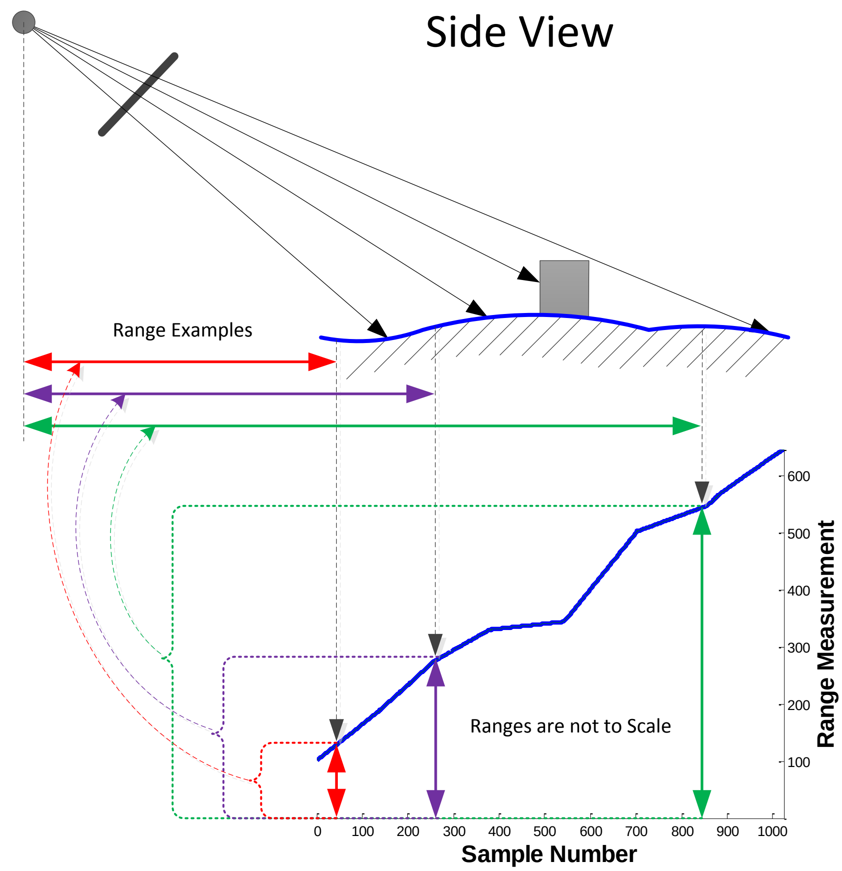

Figure 13: One Dimensional Range Measurements Illustration

Figure 13 shows 1024 Range Measurements (blue lines) along with a plot of the measurements. Three of the range measurements (red, purple and green lines) show the relationship between the physical Range values and the graph. In this example assume that the Range value is accurate to one meter and that the number of bytes to store each range value is based on the dynamic range of the measurements, which in this case is 545 meters. The value of 545 meters requires two bytes (using integers) to record this measurement. The total number of bytes for this set of range values is, therefore, 1024 measures x 2 bytes = 2048 bytes.

By fitting a line to this data set (using a least squares estimate), as shown in Figure 14, and then subtracting each range point from the line estimate, the dynamic range is reduce to 76 meters, which only requires one byte to record this measurement.

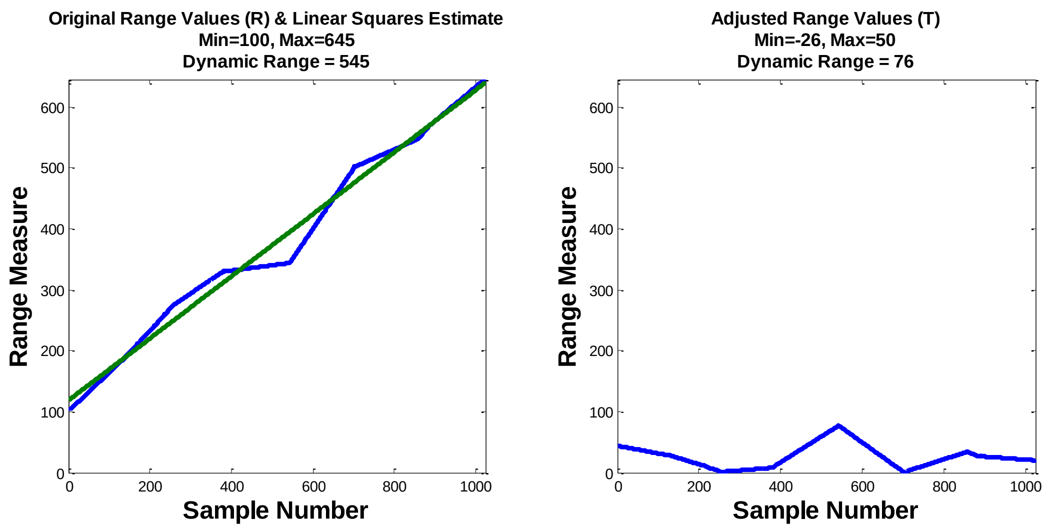

Figure 14: Illustration of Dynamic Range Reduction.

(The values in the graph on the right (Adjusted Range Values) were increased by the Minimum (-26) so all the values on the blue line would be visible in a graph with the same dynamic range as the original data on the left.)

The fitted line information must accompany the adjusted-valued data in order to reconstruct the original data. This information requires 4 bytes (2 bytes for the slope and 2 bytes for the y-intercept of a line equation of the form y = ax + b). The total number of bytes for the adjusted range values is: 1024 measures x 1 byte + 2 * 2 bytes = 1028 bytes. The overall reduction in size of bytes is nearly 50%.

The most benefit is gained when the Range Measurements demonstrate a gradual slope with minimal perturbing features. Airborne examples of gradually sloping terrain are: (1) flat, level ground viewed from an oblique angle; and (2) a hill or mountain side.

The mathematical algorithm for this example is shown with the following steps:

1) Let R be the Range Measurements r_i. F is the location, i, of each r_i in the series along with a constant value of one.

$$F = \begin{bmatrix} 1 & 1 \\ 2 & 1 \\ \vdots & \vdots \\ N & 1 \end{bmatrix}$$ Equation 1

2) Compute the linear least squares fit, generating the a, b coefficients for the $y = a * i + b$ linear estimate equation.

$$\begin{bmatrix} a \\ b \end{bmatrix} = (F^T * F)^{-1} * F^T * R$$ Equation 2

3) For each Range Measurement subtract the linear estimate.
Let P be the adjusted Range Measurements, p_i.

$$p_i = r_i - (a * i + b)$$ Equation 3

7.1 Plane Subtraction

The previous examples one dimensional case can be extended to two dimensions however with the actual range data it is possible to have unknown values in the Range Measurements. To compensate for the missing data a data mask, M, is created to zero out and essentially remove values from the computations. The mathematical algorithm is shown below in the following steps:

1) Compute Mask M from Range Measurements

$$M = \begin{bmatrix} m_{1,1} \\ m_{2,1} \\ m_{3,1} \\ \vdots \\ m_{N,1} \\ m_{1,2} \\ m_{2,2} \\ \vdots \\ m_{N,2} \\ m_{1,3} \\ \vdots \\ m_{N,M} \end{bmatrix} \qquad \text{Equation 4}$$

$$\text{Where } m_{i,j} = \begin{cases} 1 & if\ r_{i,j}\ is\ a\ valid\ value \\ 0 & if\ r_{i,j}\ is\ a\ NaN\ value \end{cases} \qquad \text{Equation 5}$$

2) Let R be the Range Measurements of a two dimensional NxM image with each element denoted as $r_{i,j}$. $\vec{R}$ is formed from R by vectorizing the image into one long vector and applying the mask. Note: ⊛ is point-wise multiplication.

$$\vec{R} = \begin{bmatrix} r_{1,1} \\ r_{2,1} \\ r_{3,1} \\ \vdots \\ r_{N,1} \\ r_{1,2} \\ r_{2,2} \\ \vdots \\ r_{N,2} \\ r_{1,3} \\ \vdots \\ r_{N,M} \end{bmatrix} \circledast M \qquad \text{Equation 6}$$

3) F is the location, *i,j* of each $r_{i,j}$ in the series along with a constant value of one. Note: ⊛ is point-wise multiplication.

$$F = \begin{bmatrix} 1 & 1 & 1 \\ 2 & 1 & 1 \\ 3 & 1 & 1 \\ \vdots & \vdots & \vdots \\ N & 1 & 1 \\ 1 & 2 & 1 \\ 2 & 2 & 1 \\ \vdots & \vdots & \vdots \\ N & 2 & 1 \\ 1 & 3 & 1 \\ \vdots & \vdots & \vdots \\ N & M & 1 \end{bmatrix} \circledast [M \quad M \quad M] \qquad \text{Equation 7}$$

4) Compute the planer least squares fit using $y = a * i + b * j + c$ to compute the a, b and c coefficients for the planer estimate equation.

$$\begin{bmatrix} a \\ b \\ c \end{bmatrix} = (F^T * F)^{-1} * F^T * \vec{R} \qquad \text{Equation 8}$$

5) For each Range Measurement subtract the planer estimate. Let P be the Adjusted Range Measurements with each element of the image denoted as $p_{i,j}$.

$$p_{i,j} = r_{i,j} - (a * i + b * j + c) \qquad \text{Equation 9}$$

Normally, it is not recommended to use least squares to produce the coefficients because of possible numerical stability in the results. Typically other methods are used such as QR factorization however in this situation the results only produce a reference plane that is then used in reverse for the decompressing and obtaining the original Range Measurements.

7.2 Reverse Plane Subtraction

To reverse the plane subtraction processing the following equation is used:

$$r_{i,j} = p_{i,j} + (a * i + b * j + c) \qquad \text{Equation 10}$$

The parameters a, b and c are stored with the adjusted range measurements.