PDS4 Hayabusa LIDAR Bundle Overview

(urn:nasa:pds:hay.lidar)
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1. Introduction

Hayabusa was a JAXA mission to the near-Earth asteroid 25143 Itokawa. It was launched on May 9th 2003 and returned to Earth on June 13th 2010. The Hayabusa spacecraft included a Light Detection and Ranging (LIDAR) altimeter. The primary objective of LIDAR was to establish the range between the Hayabusa spacecraft and the asteroid Itokawa for navigation purposes during the surveying and collection phases of the mission.The secondary scientific objective of the LIDAR included determining the mass of the asteroid, and measuring its global surface elevation and roughness. From 10 September to 25 November 2005, 4,107,104 shots were fired and 1,665,548 returns were detected.

In addition to the LIDAR instrument the other Hayabusa instruments AMICA and NIRS have also been archived in PDS, as well as higher level data. See the PDS4 Hayabusa Archive Overview in the Hayabusa Mission Information bundle (urn:nasa:pds:hay.mission) for details.

2. Modification History

In 2008, the Hayabusa LIDAR instrument data V1.0 were archived in PDS in the PDS3 archiving standard.

2.1 PDS3 V1.0 to V2.0 Update

A new optimized version of the CDRs (OPT) were generated and added to the CDR collection. The original filtered (F) and unfiltered (UF) CDRs were changed slightly in going from PDS3 version 1 to version 2. The dates in the unfiltered and filtered data filenames were changed to match the dates used in the EDR filenames, with the exception of the data collected during the last TOUCH DOWN phase. The filenames for data collected after November 18, 2005 could not be corrected. Furthermore, some duplicate data were present in the original version 1 of the LIDAR data, and these have been removed.

2.2 PDS3 to PDS4 Migration

During 2021-2022, the PDS3 Hayabusa LIDAR holdings were migrated to the PDS4 archiving standard by the Small Bodies Node, using the On-Line Archiving Facility (OLAF) and the OLAF PDS4 migration tools. The data files are unchanged.

Document and metadata changes made during the migration of the bundle include:

- No primary data files were modified.
- Metadata in the PDS3 labels were migrated to PDS4 labels.
- Mission description and spacecraft description documents have been included in the PDS4 Hayabusa Mission bundle and are not included in the LIDAR bundle.
- Documentation was in some cases rearranged and updated to meet the needs of the PDS4 bundle.
- A new bundle overview (this document) was created to describe the LIDAR bundle, incorporating information from the PDS3 data set catalog files and other documents.

3. Hayabusa LIDAR Bundle Contents

The Hayabusa LIDAR bundle contains two data collections and one document collection:

The **data_raw** collection is composed of the Experiment Data Record (EDR) dataset which is the source for the science data. All the Hayabusa LIDAR data records are ASCII tables (See section 4).

The **data_calibrated** collection contains the Calibrated Data Record (CDR) which includes LIDAR science and telemetry data that have been converted to engineering and physical units (See section 5).

The **document** collection contains the LIDAR bundle overview (The document you are reading now), the LIDAR references document, and the LIDAR instrument descriptions (See section 6).

4. The LIDAR Raw Data

4.1 Data file types and contents

The data_raw collection contains three files:

EDR20050911_20050929.TAB corresponds to data acquired during the GATE Position Phase when the HAYABUSA spacecraft was at ~20km distance from the surface of the asteroid

EDR20050930_20051028.TAB corresponds to data acquired during the HOME Position Phase when the HAYABUSA spacecraft was at 3-7km distance from the surface of the asteroid.

EDR20051029_20051125.TAB corresponds to the TOUCH DOWN phase when the HAYABUSA spacecraft attempted to sample the surface of Itokawa.

The Experiment Data Record (EDR) is the source for the science data, while the House Keeping Experiment Data Record (HKEDR) and telemetry provide the data needed to determine the position of the HAYABUSA spacecraft relative to the asteroid. Resulting orbit, geometric, and calibration data have been incorporated, to determine the location of the LIDAR boresight on the surface of the asteroid provided in the CDR. With an appropriate shape model and density estimates for Itokawa, these can be used to obtain topographic profiles of the surface, e.g. [CHENGETAL2002] of Itokawa. The housekeeping (HKEDR) file has not been included in the archive because the mission has not yet given permission for it to be archived in PDS. When permission is given to archive it, it will be added.

Each EDR contains three columns of data. The first column is the the Mission Elapsed Time in units of spacecraft ticks when the LIDAR range was measured. One spacecraft tick equals 1/32 of a second. The second column is equal to this same time but translated into units of Universal Coordinated Time UTC. The third column equals the range measured by the LIDAR at the time indicated. The LIDAR collected data at 1 Hz (1 return per second) for the entire duration of the encounter with Itokawa (~3 months).

The EDR is composed of three files: EDR20050911_20050929.TAB which corresponds to data acquired during the GATE Position Phase when the HAYABUSA spacecraft was at ~20km distance from the surface of the asteroid; EDR20050930_20051028.TAB which corresponds to data acquired during the HOME Position Phase when the HAYABUSA spacecraft was at 3-7km distance from the surface of the asteroid; EDR20051029_20051125.TAB which corresponds to the TOUCH DOWN phase when the HAYABUSA spacecraft attempted to sample the surface of Itokawa.

5. The LIDAR Calibrated Data

5.1 Data file types and contents

The data_calibrated collection is composed of the CDR dataset which contains three kinds of data.

The first is an unfiltered (**UF**) version of the data after the processing described in the next section was undertaken.

The second is composed of the same set but was filtered (**F**) to remove any estimated surface point which was located more that 10m from the predicted intersection of the vector defining the pointing of the LIDAR boresight and the shape model of the asteroid.

The third is an optimized (**OPT**) version that is built on the filtered data.

The filenames include F, UF and OPT respectively. The CDR files include information on both the Hayabusa LIDAR and the boresight of the Near Infra-Red Spectrometer aboard

Hayabusa. The NIRS data is provided as a courtesy to others Hayabusa related efforts because it is exactly aligned with the LIDAR.

All three filtered, unfiltered and optimized CDR files list the following data in their column order:

1. The spacecraft mission elapsed time (MET)
2. The equivalent spacecraft time in UTC The X,Y and Z estimate of the spacecraft location derived during the LIDAR data processing (see processing section below)
3. The estimated X,Y,Z position of the LIDAR and Near Infra-Red Spectrometer (NIRS; Coaligned with the LIDAR) footprint using the LIDAR processed spacecraft position, the LIDAR boresight vector, and the measured range.
4. The predicted X,Y,Z position of the LIDAR footprint at the intersection of the LIDAR boresight vector with the a high resolution asteroid shape model [GASKELLETAL2008B] using the LIDAR processed spacecraft position.
5. Incidence, emission and phase angle of the center of the LIDAR/NIRS field of view (FOV) using the interection of the LIDAR boresight vector with a high resolution asteroid shape model [GASKELLETAL2008B], using the LIDAR processed spacecraft position.
6. Size in m of the LIDAR and NIRS FOV obtained from the LIDAR FOV and measured LIDAR range to surface of the asteroid.
7. Longitude and latitude of the center of the LIDAR/NIRS (FOV) using the measured LIDAR range, and the spacecraft positions given by the LIDAR processing.
8. Predicted longitude and latitude of the LIDAR/NIRS (FOV) at the intersection of the
9. LIDAR boresight vector with the asteroid shape model [GASKELLETAL2008B], using the spacecraft positions given by the LIDAR processing.
10. Mean incidence, emission and phase angle from nine locations across the FOV of NIRS that were derived from nine vectors across the NIRS FOV (split into a 3x3 grid) whose intersection with the shape model [GASKELLETAL2008B] were determined using the spacecraft positions given by the LIDAR processing.
11. Mean longitude and latitude of the NIRS FOV for the up to nine vectors within the NIRS FOV that intersect the asteroid shape model using the spacecraft positions given by the LIDAR processing.
12. Predicted minimum and maximum longitude and latitude of the up to nine vectors within the NIRS FOV that intersect the asteroid shape model using the spacecraft positions given by the LIDAR processing.
13. Number of vectors within the NIRS FOV (split into a 3x3 grid) that intersects the asteroid shape model using the spacecraft positions given by the LIDAR processing. This number of vectors was used in the calculation to estimate the previous mean incidence, emission and phase of NIRS, and the mean, minimum and maximum longitude and latitude values of NIRS.

5.2 Processing

The CDR incorporates the best orbital solutions and LIDAR boresight locations derived by the Hayabusa LIDAR team. As a first step, a new algorithm was developed to better locate the Hayabusa spacecraft relative to the asteroid. The most important data initially used was the housekeeping (HKEDR) data of the x-y pixel of the illuminated centroid obtained by the ONCW1 (WAC) camera of AMICA. Additional data included the project supplied information on the pointing of the WAC (SPICE C-kernels), as well as a good shape model of Itokawa (generated by R. Gaskell and part of the Hayabusa PDS delivery [GASKELLETAL2008B]). Our algorithm assumes that the spacecraft attitude (i.e., its pointing) provided by the SPICE C kernels as determined by the on board star cameras remained correct throughout the mission.

The algorithm consists of first using a preliminary spacecraft location, the spacecraft attitude data and the shape model to create simulated images of Itokawa as seen by the WAC at the time the actual HKEDR was acquired. A predicted x-y pixel location for the illuminated centroid was computed from these simulated images simultaneously with a predicted range to where the LIDAR was pointing at the surface of the Itokawa. These predicted HK-data were then compared to the actual HKEDR in order to correct the spacecraft position. This comparison was repeated iteratively until the predicted and actual x-y pixel locations were within 0.1 pixel, and the predicted and measured ranges were within 0.5 to 3 m of each other, depending on the range of the spacecraft relative to the surface of the asteroid.

The algorithm used to reproduce the HK data provides at 2 min intervals excellent estimates of the spacecraft position relative to Itokawa for most of the time that Hayabusa observed Itokawa. The data acquired by the LIDAR, however, was taken at 1 s intervals. Therefore, good estimates of the spacecraft position were still required for those periods between when HK data was acquired. After some trial and error, good estimates were obtained by initially using linear interpolation to first guess the locations of the spacecraft between those estimates provided by the HK data. The LIDAR team then fit all the positions using least squares to a second order polynomial or parabolic function between spacecraft maneuvers. Such a function should have a form that compares favorably with solutions to the semi-orbital equation of motion for the Hayabusa spacecraft that include the solar pressure acting on the spacecraft, because major maneuvers occurred fairly frequently (between a few hour to a few day intervals). Analysis of the resulting data indicate significant improvements on how well the new trajectory estimate for Hayabusa relative to what was initially provided by the project in the form of SPICE SP-Kernels.

Further processing was then performed, where the following algorithm was used to improve the unfiltered lidar data. First, the lidar points were divided into subsets of no more than 1000 points each. The actual number or points per set was chosen so that the size of a bounding box containing the points did not completely wrap around the asteroid. Then for each lidar point in the set, a point on the asteroid near it was computed by intersecting with the asteroid (using the highest resolution shape model of Itokawa produced by Bob Gaskell) a ray originating from the spacecraft position in the direction of the lidar point. These intersection points were grouped together to form a second set of points in addition to the original (uncorrected) lidar points. A point matching scheme was then employed to find the optimal translation of the first set of points so that the distance between the lidar footprints and shapemodel were minimized. This optimal translation was then applied to the original lidar points and spacecraft positions to produce the improved data. This procedure was repeated for each subset of the lidar data.

The LIDAR team provide three CDR files for each time range. The first includes boresight locations that have not been further filtered after the first set of above processing prior to optimization was undertaken. The second set filters the unfiltered version of the data to remove bad data in the filtered set: any estimated surface point which was located more that 10m from the predicted intersection of the vector defining the pointing of the LIDAR boresight and the shape model of the asteroid were removed. This difference of 10m was chosen because most small scale variations in surface topography on Itokawa are less than this amount. This second set results in ~65% of the LIDAR points being useful. This is equal to ~1.0 million LIDAR shots. The third optimized data set was able to use most of the unfiltered data to further increases the number of usable LIDAR points to ~1.3 million LIDAR shots. The EDR contains a total ~1.6 million LIDAR data originally collected by Hayabusa. The optimized data also provided some of the best estimates of the location of the Hayabusa spacecraft relative to the asteroid.

6. The Hayabusa LIDAR Document Collection

The Document collection contains three documents:

The document you are reading now, the **LIDAR_Bundle_Overview.pdf** describes the contents of the hay.lidar bundle.

The **LIDAR_Instrument_Description.txt** describes the LIDAR instrument.

The **LIDAR_References.pdf** lists all the references for the Hayabusa LIDAR bundle.

7. Ancillary Data

As part of analysis, the LIDAR team found that the AMICA SPICE image kernel needed further modification. A new version (amica_v202.ti) was prepared by Olivier Barnouin-Jha. In order to generate the CDR dataset, the LIDAR team used several project provided SPICE kernels including the planetary ephemeris kernel pck00008.tpc, the Itokawa Ephmeris and rotation kernel sb_25143_140.bsp and the Hayabusa clock kernel hayabusa.tsc (the version of 2005-09-06). These and the other SPICE kernels used to prepare the data files have been archived in the PDS SPICE archives.

8. Coordinate System

A planetocentric coordinate system is employed, which is body-centered, using the center- offigure as the origin. The actual vector from the center of Itokawa to the surface should be primarily employed for scientific purposes because of the important curvature of Itokawa where some locations can possess more than one latitude and longitude. However, latitude and longitude data are also provided, but should be used with caution. The latitude is defined by the angle between the equatorial plane and a vector extending from the origin of the coordinate system to the relevant point on the surface. Latitude is measured from -90 degrees at the south pole to +90 degrees at the north pole. Longitude extends from 0 to 360 degrees, with values increasing eastward (i.e., it is a right-handed coordinate system) from the prime meridian. This coordinate system is preferred for use in navigation and geophysical studies in which, for example, estimates of elevation or gravitational potential are generated mathematically.

9. Confidence Level Overview

9.1 Resolution

The resolution of the data is about 50 cm vertically. Along track spacing is variable. Small errors in the Hayabusa emphemeris solutions and pointing knowledge yield uncertainties in absolute ground spot location to within 10 m, but is often better in the case of the filtered and unfiltered data. The optimized (OPT) CDR data set has errors relative to the Itokawa shape model that are on the order of 3.5 m.

The housekeeping (HKEDR) file has not been included in the archive because the mission has not yet given permission for it to be archived in PDS. When permission is given to archive it, it will be added. The House Keeping Experiment Data Record (HKEDR) and telemetry provide the data needed to determine the position of the HAYABUSA spacecraft relative to the asteroid. Resulting orbit, geometric, and calibration data have been incorporated, to determine the location of the LIDAR boresight on the surface of the asteroid provided in the CDR. With an appropriate shape model and density estimates for Itokawa, these can be used to obtain topographic profiles of the surface, e.g. [CHENGETAL2002] of Itokawa.

The confirmed time resolution of the HAYABUSA lidar equals aproximately 1.67ns which is equivalent to 0.5m in range. This values was derived from the data obtained over the very flat and smooth Muses-C Regio. See [BARNOUIN-JHAETAL2008]. For further information about the Hayabusa LIDAR and its data set may be found in [MUKAIETAL2006] and [BARNOUINJHAETAL2008]

The first three columns of this HKEDR are identical to those in the EDR file. The next two columns provide the illuminated centroid of Itokawa within the reference frame of the wide angle camera, ONC-W1. This camera is part of the AMICA instrument package and more information is given in the description for that instrument. In brief, it is a 512 by 512 pixel imager with a field of view of 60 degrees.

The software aboard the HAYABUSA spacecraft imager found the centroid of the largest illuminated object in the field of view of this ONC-W1, with DN values greater than a threshold of 5DN. This happened at 2 min intervals, and was accompanied by a LIDAR range and time listed in the first three columns of the HKEDR file already discussed. The first of the two pixel values gives the x or sample location of the centroid. The second one gives the y or line location of the centroid. The one HKEDR file includes data for the entire mission. A pixel value for x and y of zero implies the asteroid filled the entire field of view of the ONC-W1.

9.2 Timing uncertainty

The clock aboard Hayabusa possesses an estimated uncertainty of +/- 12 seconds due to a periodicity in the control and operation of the analog signal processing unit. This effect was somewhat remedied by the analysis used by the LIDAR science team. The relative pointing between the ONC-W2 camera and AMICA were statically adjusted so that a simulated image using the Hayabusa shape model would match the location of Itokawa observed by AMICA. Both data sets suffer from the same timing problem and our approach would thus have minimized their effect over the lifetime of the mission. Additional errors due to this timing uncertainty are captured by the 10m uncertainty clearly established to be the accuracy of the LIDAR CDR filtered data. Examples of the excellent match between the topography observed, the estimated location of the boresight using the LIDAR CDR dataset and observations of where this boresight should be in AMICA all indicate that this problem has a minor impact on the quality of the Hayabusa LIDAR data set (see Barnouin-Jha et al. [2008] for additional details.)

9.3 Limitations

The Hayabusa LIDAR data has met many of its design expectations. It has demonstrated a measurement precision of ~50 centimeters over flat terrain. After processing, more than 82 % of the data was found useful for topographic analyses, with average errors of 3.5 m or less.”

10. References

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